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FUTURE AUTOMATED SPACE MISSION REQUIREMENTS

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Edgar M. Cortright
Deputy Associate Administrator for
Space Science and Applications
National Aeronautics and Space Administration

NASA/Electronics Industries Association briefing
on Aerospace Electronic Systems Technology
Cambridge, Massachusetts
May 3, 1967

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FUTURE AUTOMATED SPACE MISSION REQUIREMENTS

Edgar M. Cortright
Deputy Associate Administrator for
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The long range plans of the National Aeronautics and Space Administration continue to place heavy reliance on automated spacecraft. This strategy is based on nine years of highly successful and rewarding experience with such equipment.

During the past two years, automated spacecraft have demonstrated striking advances in effectiveness, durability, and versatility. They have provided most of our new scientific data from space, and they have yielded most of our practical applications of space flight.

Presented at the NASA/EIA Briefing on Aerospace Electronic Systems Technology, Cambridge, Massachusetts, May 3, 1967.

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During the next few years, man will emerge as a useful explorer, experimenter, and operator in space. His attention, however, will generally be directed to those areas which can make _in situ_ use of his unique capabilities as a thinking servomechanism. For exploring the farthest reaches of space, for probing its most unknown and hazardous regions, for continuous monitoring of its many diverse phenomena, for day-in day-out practical utility, and as the precursors of all space activity, automated spacecraft will remain our mainstay.

The previous paper has outlined some of our future manned space mission planning. This paper will review the results of several years of planning for future automated space missions. Together, they should depict the balanced mix of automated and manned missions which will characterize the space program of the 1970's.

Most of the new mission opportunities which I will discuss today are further defined in the program description documents which have been provided you as handouts.

AUTOMATED SPACECRAFT FLIGHT RECORD
(Fig. 1)

This figure formalizes the spacecraft performance record since the beginning of the United States space program in 1958. The list excludes 28 attempted flights where launch vehicle failures did not give the spacecraft an opportunity to perform. All but four of these occurred prior to 1963. Some of the very early missions such as the early lunar Pioneers have been somewhat arbitrarily designated successful despite limited mission results because the spacecraft themselves performed satisfactorily. In general, this figure indicates a 98% success record for the spinning or tumbling spacecraft, a 70% success record for 3-axis stabilized spacecraft, and an overall record of 90% successful. Furthermore, the complex lunar, planetary, and interplanetary spacecraft have achieved a record of 11 successes out of the last 12 flights.

AUTOMATED SPACECRAFT FLIGHT RECORD

JANUARY 1958 TO APRIL 1967

SPACECRAFT	SUCCESS	FAILURE
SCIENTIFIC SATELLITES		
EXPLORER CLASS (INCLUDING GEODETIC)	34	0
INTERNATIONAL	6	0
ORBITING SOLAR OBSERVATORY	3	0
ORBITING GEOPHYSICAL OBSERVATORY	1	2
ORBITING ASTRONOMICAL OBSERVATORY	0	1
BIOSATELLITE	0	1
PEGASUS	3	0
	4[illegible]	4
METEOROLOGICAL SATELLITES		
TIROS	10	0
TIROS OPERATIONAL SATELLITE (ESSA)	4	0
NIMBUS	2	0
	1[illegible]	0
COMMUNICATIONS AND TECHNOLOGY SATELLITES		
ECHO	2	0
TELSTAR	2	0
RELAY	2	0
SYNCOM	2	1
INTELSAT	3	1
APPLICATIONS TECHNOLOGY SATELLITE	1	0
	12	2
LUNAR PROBES		
PIONEER	4	0
RANGER	3	4
SURVEYOR	1	[illegible]
ORBITER	3	[illegible]
	11	[illegible]
PLANETARY AND INTERPLANETARY PROBES		
PIONEER	3	0
MARINER	2	0
	5	0
	91	11

NOTE: LAUNCH VEHICLE FAILURES EXCLUDED

NASA S67-2178
4-14-67

Figure 1

AUTOMATED SPACECRAFT DEVELOPMENT EXPERIENCE
(Fig. 2)

This figure presents pertinent statistics on the development cost and times for some of the major automated spacecraft (including experiments). The following items are noteworthy:

Scientific and Geodetic Satellites

Explorer class satellites are currently running about $7 million per spacecraft.

The Orbiting Solar Observatory, costing $10 million per spacecraft and $17 thousand per pound, continues to constitute a best buy in fully stabilized systems. It has a very high ratio of experiment-to-gross weight.

Meteorological Satellites

The Environmental Science Services Administration (ESSA) satellites at $3 million per spacecraft and $10 thousand per pound constitute a best buy among spin-stabilized earth satellites of all types. There has never been a mission failure of the TIROS satellites.

Communications and Technology Satellites

Our experience in this areas has been outstanding. The SYNCOM satellite was among the most productive in terms of results and economy. The more recent and ambitious Applications Technology Satellite continued this pattern with schedule and cost performance within 10% of that projected in the initial contract.

Lunar, Planetary and Interplanetary Probes

The Lunar Orbiter and the Mariner IV are comparable developments and represent our best experience with complex second generation 3-axis attitude stabilized spacecraft. Both systems were developed in a very short period of time and adhered closely to schedule. As can be seen, the cost per pound was comparable for these systems and indicates that for spacecraft of this weight and complexity, development costs approaching $50 thousand per pound can be expected.

AUTOMATED SPACECRAFT DEVELOPMENT EXPERIENCE

	NUMBER OF SPACECRAFT	TOTAL COST INCLUDING DEVELOPMENT (MILLIONS OF DOLLARS)	COST PER SPACECRAFT (MILLIONS OF DOLLARS)	WEIGHT, DRY (POUNDS)	COST PER POUND (THOUSANDS OF DOLLARS)	DEVELOPMENT TIME TO FIRST FLIGHT* (MONTHS)
SCIENTIFIC AND GEODETIC SATELLITES						
● EXPLORERS						
IMP	10	57	6	140	43	26
RADIO ASTRONOMY	2	14	7	415	17	35**
GEOS	2	13	7	385	18	13
● BIOSATELLITE	6	135	22	950 1250	20	32
● ORBITING SOLAR OBSERVATORY	8	80	10	600	17	29
● ORBITING GEOPHYSICAL OBSERVATORY	6	220	37	1300	28	44
● ORBITING ASTRONOMICAL OBSERVATORY	4	280	70	4200	17	63
METEOROLOGICAL SATELLITES						
● TIROS OPERATIONAL SATELLITE (ESSA)	9	26	3	300	10	19
● NIMBUS	4	200	50	930 1160	48	46
COMMUNICATIONS AND TECHNOLOGY SATELLITES						
● SYNCOM	3	21	7	80	87	18
● APPLICATIONS TECHNOLOGY SATELLITE	5	130	26	800	33	31
LUNAR PROBES						
● RANGER	9	170	19	675 800	26	20
● SURVEYOR	7	483	69	596 624	113	62
● ORBITER	5	167	33	565	58	29
PLANETARY AND INTERPLANETARY PROBES						
● MARINER II	3	30	10	450	22	12
● MARINER IV	3	84	28	575	49	24
● PIONEER	5	67	13	145	90	28

*FROM CONTRACT GO-AHEAD
**FIRST FLIGHT SCHEDULED FOR NOV. 1967

NASA S67-2179
4-27-67

Figure 2

AUTOMATED SPACECRAFT LIFETIMES - HIGHLIGHTS
(Fig. 3)

This figure summarizes our best experience in achieving long lifetimes of automated spacecraft. Among the spinning satellites, a 4-year capability has been demonstrated by SYNCOM, TIROS, and Alouette. The Orbiting Geophysical Observatory-1 (despite the early failure of the 3-axis attitude control system) has demonstrated nearly a 3-year lifetime for a highly complex assembly of instruments and data-conditioning and telemetry equipment. Nimbus II and Mariner IV, however, have demonstrated the potential long life of 3-axis stabilized systems. Surveyor and Orbiter have demonstrated a capability of achieving 100% design lifetimes on exceedingly complex missions in orbit about the Moon and on the lunar surface.

It is important to note however that many other automated systems which performed sufficiently well to be designated mission successes in Figure 1 did not in fact achieve their design lifetimes with all experiments and subsystems functioning properly.

AUTOMATED SPACECRAFT LIFETIMES-HIGHLIGHTS

	USEFUL LIFETIME, MONTHS (TO APRIL 1967)
SCIENTIFIC AND GEODETIC SATELLITES	
ALOUETTE I	55·
OGO I*	32·
METEOROLOGICAL SATELLITES	
TIROS VII	46·
NIMBUS II	11·
COMMUNICATIONS SATELLITES	
SYNCOM II	45·
RELAY II	39·
LUNAR PROBES	
SURVEYOR I	>1 (100%)
ORBITER I	>2 (100%)
PLANETARY AND INTERPLANETARY PROBES	
MARINER IV	29·
PIONEER VI	16+

*LESS ATTITUDE CONTROL
+ STILL OPERATING

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4-14-67

Figure 3

DESIRED IMPROVEMENTS
(Fig. 4)

The earlier figures were designed to demonstrate our highly successful experience with automated equipment. A great deal remains to be accomplished with such equipment however. We should achieve average lifetimes of greater than 3 years for spin-stabilized spacecraft and greater than 2 years for the 3-axis stabilized systems. There is really no reason why 5 years or more cannot be achieved for many of the missions designed for routine monitoring and/or operational service. Whereas some projects have done remarkably well in holding to schedule and cost targets, the average space project has a history very similar to other types of large national research and development programs. Schedule and cost slippages have averaged about 70% from the initiation of phase C effort, and somewhat higher based on preliminary estimates. We should have as our goal holding both schedule and cost to within 10% of our initial targets.

DESIRED IMPROVEMENTS

- INCREASED AVERAGE LIFETIME IN SPACE
  - SPIN STABILIZATION > 3 YEARS
  - ACTIVE STABILIZATION > 2 YEARS
- IMPROVED SCHEDULE PERFORMANCE $< 10\%$ SLIP
- IMPROVED COST PERFORMANCE $< 10\%$ OVERRUNS

NASA S67-2181
4-14-67

Figure 4

HOW TO IMPROVE
(Fig. 5)

I have listed here some of the prime areas on which government agencies and their aerospace contractors must concentrate if we are to achieve the performance goals which we have set. Whereas some of these areas fall into the "for motherhood and against sin" category, they should not be dismissed as trite. As a matter of fact, all of these areas have caused serious problems at one time or another among the multiplicity of projects which we have conducted.

Since some programs have largely avoided these pitfalls, others can too. It is up to management to provide the leadership to shed complacency and poor practices where they exist. The space business demands an unflagging dedication to excellence.

HOW TO IMPROVE

- REALISTIC OBJECTIVES AND SCHEDULES
- MORE THOROUGH SYSTEMS ENGINEERING
- SIMPLICITY WHERE POSSIBLE
- LARGER DESIGN MARGINS
- ADEQUATE WEIGHT CONTINGENCY
- MORE REDUNDANCY
- FEWER SINGLE POINTS OF FAILURE
- BETTER HIGH RELIABILITY PARTS
- MORE RIGOROUS R&QA IMPLEMENTATION
- BETTER WORKMANSHIP
- MORE THOROUGH TESTING
- INCREASED SENSE OF RESPONSIBILITY AND ACCOUNTABILITY
- MORE INCENTIVES FOR PERFORMANCE AT ALL LEVELS
- FEWER CHANGES DURING DEVELOPMENT

NASA S67-2182
4-14-67

Figure 5

FUTURE USES OF AUTOMATED SPACECRAFT (1967-1985)
(Fig. 6)

This figure summarizes most of the areas of activity in space in which we will be engaged for the next 15 to 20 years. I have indicated the probable preferred orbits for these mission categories and the minimum mission lifetimes which will be acceptable. Based on these projected requirements and our prior experience, I have attempted to summarize the suitability of automated and manned spacecraft for these space missions. Obviously, both are required and the proper mix is a matter of judgment based on cost effectiveness, growth potential, prestige, and what the competition is doing. Generally speaking, automated spacecraft are suitable for nearly all of these missions. In about half the cases, the automated approach appears to be the most practical. In the remaining cases, both automated and manned spacecraft are applicable. While the automated equipment is generally more cost effective, manned systems in some cases have more growth potential.

FUTURE USES OF AUTOMATED SPACECRAFT (1967-1985)

	PREFERRED ORBITS		EXPECTED	SPACECRAFT
	ALTITUDE	INCLINATION	LIFETIMES	SUITABILITY
EARTH:				
AERONOMY	LOW	POLAR AND EQUATORIAL	>1 YR	AUTOMATED
MAGNETOSPHERE	BOTH LOW (A) AND HIGHLY ELLIPTICAL (B)	(A) HIGH (B) LOW	>1 YR	AUTOMATED
GEODESY	LOW	VARIED	>1 YR	AUTOMATED
INTERPLANETARY: SOLAR AND INTERPLANETARY PROBES	ESCAPE	—	>2 YR	AUTOMATED
SUN AND STARS:				
OPTICAL ASTRONOMY	LOW	POLAR	≈1 YR	AUTOMATED MANNED
RADIO-ASTRONOMY	HIGH	LOW	≈1 YR	AUTOMATED MANNED
MOON: PLANETOLOGY	ESCAPE	—	>1 MO	AUTOMATED MANNED
PLANETS: PLANETOLOGY/EXOBIOLOGY	ESCAPE	—	>2 YR	AUTOMATED MANNED
BIOLOGY:				
BASIC	LOW	LOW	1-3 YR	AUTOMATED MANNED
AEROMEDICAL	LOW	LOW	1-3 YR	MANNED
APPLICATIONS:				
METEOROLOGY	BOTH LOW (A) AND SYNCHRONOUS (B)	(A) NEAR-POLAR (B) EQUATORIAL	1-3 YR	AUTOMATED
COMMUNICATION	SYNCHRONOUS	EQUATORIAL	>3 YR	AUTOMATED
NAVIGATION AND TRAFFIC CONTROL	SYNCHRONOUS	EQUATORIAL	>3 YR	AUTOMATED
EARTH RESOURCES	LOW	NEAR-POLAR	>6 MO	AUTOMATED/MANNED
TECHNOLOGICAL : LABORATORY R&D	LOW	LOW	>1 YR	MANNED

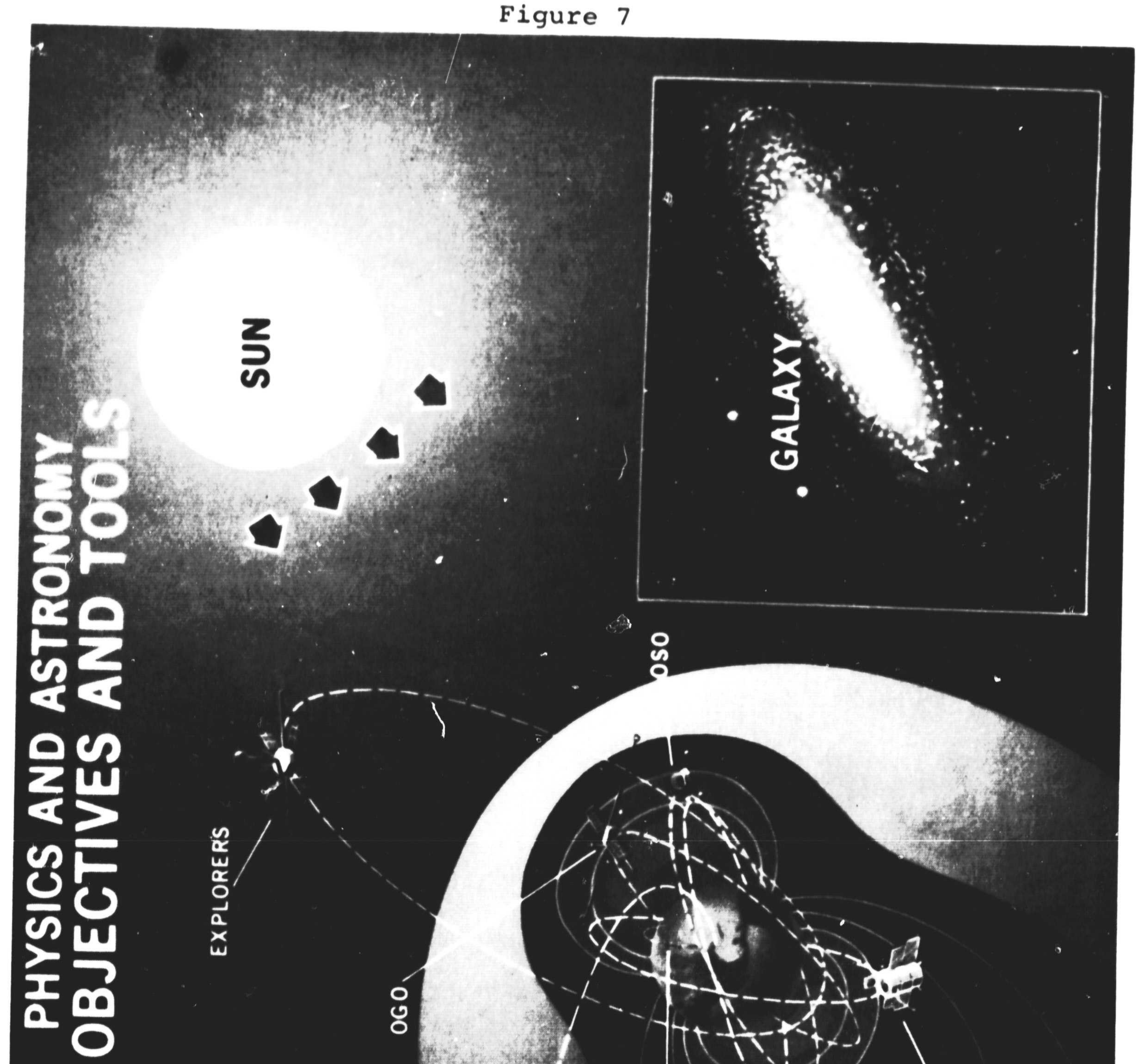
NASA S67-2183
4-14-67

Figure 6

PHYSICS AND ASTRONOMY - OBJECTIVES AND TOOLS (Fig. 7)

The Physics and Astronomy program is conducted with a diverse mix of earth satellites and deep space probes. Explorers are used to investigate and monitor the earth's atmosphere, ionosphere, magnetosphere and the interplanetary medium immediately beyond the magnetosphere boundary. In addition, some Explorers are being designed to carry out preliminary astronomical studies in the radio and X-ray portions of the electromagnetic spectrum. The Pioneer interplanetary probes extend our measurements of solar radiation from the vicinity of the earth to widely-separated positions around the sun. Earth-orbiting observatories have been developed to carry out more sophisticated observations of the magnetosphere, the sun, and the stars than are possible with the simple Explorers. These equipments are being supplemented by manned observatories such as the Apollo Telescope Mount which provide resolutions not yet available with automated equipment but for shorter duration. From our experience with these early observatories will come the systems of the 70's.

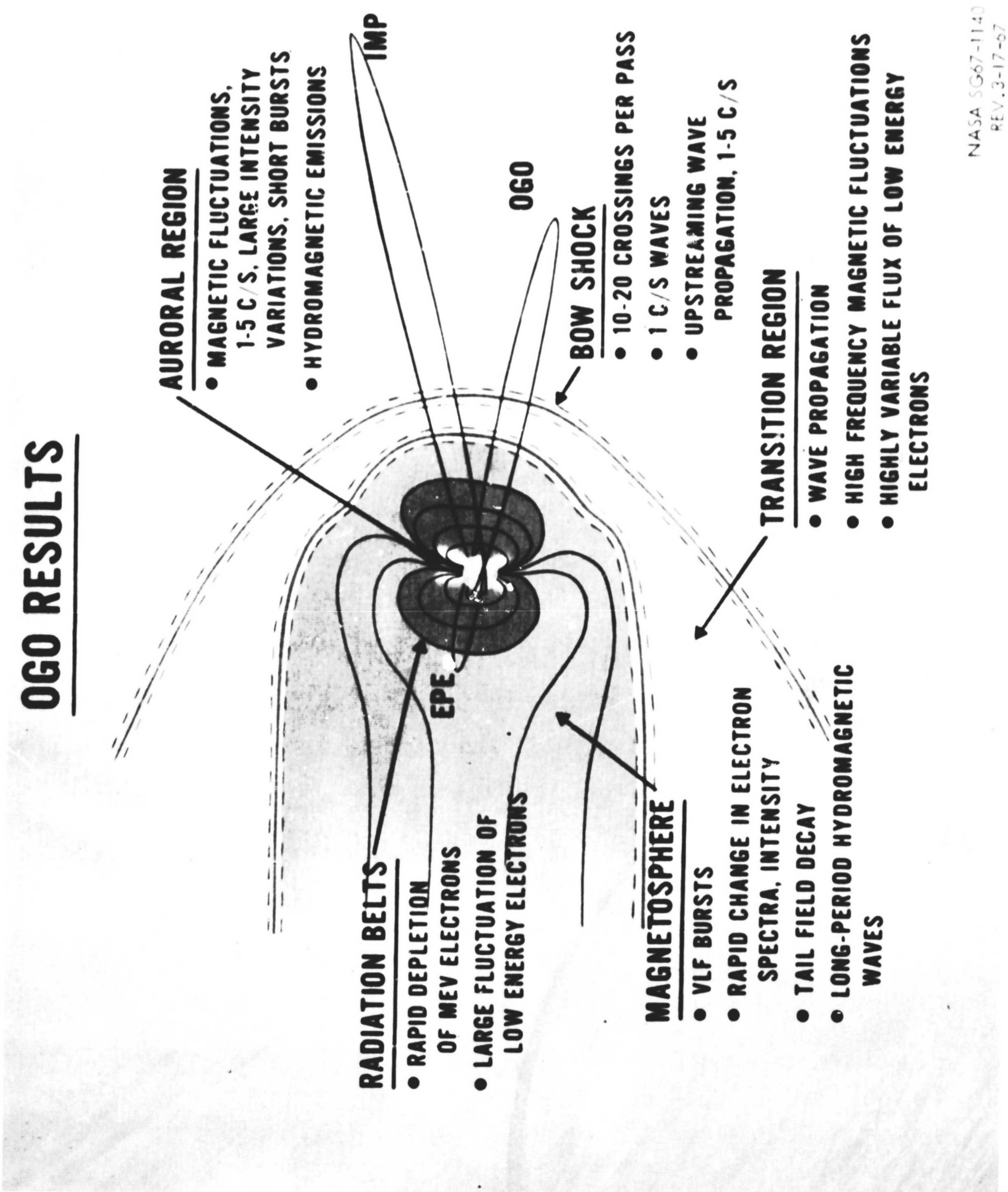
Figure 7


PHYSICS AND ASTRONOMY
OBJECTIVES AND TOOLS
SUN
GALAXY
OSO
EXPLORERS
OGO
INTERPLANETARY PROBES
SOUNDING ROCKET
ATM
OAO

ORBITING GEOPHYSICAL OBSERVATORY
(Fig. 8)

The results of our magnetosphere studies are illustrated in this figure. By carrying as many as 20 separate scientific experiments and a very high bandwidth data communications system, the OGO's have permitted a very detailed high resolution examination of the earth's magnetosphere. The data output of the OGO's has exceeded that of all other scientific earth-orbiting spacecraft to date. The prime result emerging from these data to date has been an appreciation of the fluctuating and dynamic nature of the earth's magnetosphere caused by the unsteady influence of the solar wind and intermittent solar disturbances.

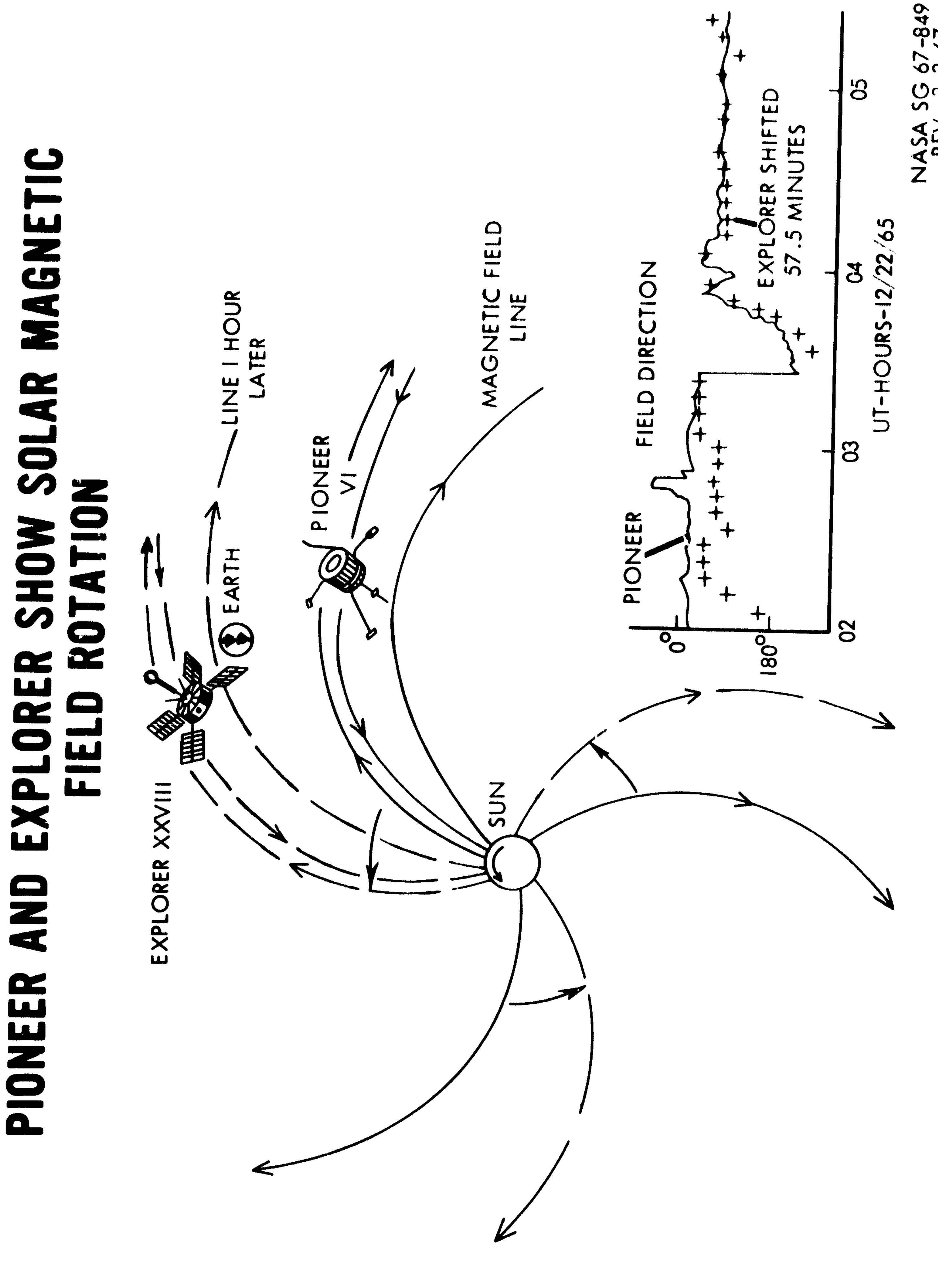
Figure 8


OGO RESULTS
AURORAL REGION
• MAGNETIC FLUCTUATIONS, 1-5 C/S, LARGE INTENSITY VARIATIONS, SHORT BURSTS
• HYDROMAGNETIC EMISSIONS
IMP
OGO
BOW SHOCK
• 10-20 CROSSINGS PER PASS
• 1 C/S WAVES
• UPSTREAMING WAVE PROPAGATION, 1-5 C/S
TRANSITION REGION
• WAVE PROPAGATION
• HIGH FREQUENCY MAGNETIC FLUCTUATIONS
• HIGHLY VARIABLE FLUX OF LOW ENERGY ELECTRONS
EPE
RADIATION BELTS
• RAPID DEPLETION OF MEV ELECTRONS
• LARGE FLUCTUATION OF LOW ENERGY ELECTRONS
MAGNETOSPHERE
• VLF BURSTS
• RAPID CHANGE IN ELECTRON SPECTRA, INTENSITY
• TAIL FIELD DECAY
• LONG-PERIOD HYDROMAGNETIC WAVES
NASA SG67-1140
REV. 3-17-67

PIONEER AND EXPLORER SHOW SOLAR MAGNETIC FIELD ROTATION
(Fig. 9)

Whereas the Orbiting Geophysical Observatory spacecraft has studied the effect of solar disturbances on the earth from within the magnetosphere, our Pioneers and Interplanetary Monitoring Platforms have flown beyond the boundaries of the earth's magnetosphere to make direct measurements of the solar radiation particles and fields. This figure shows how the widely separated Pioneer VI and Explorer XXVIII demonstrated the rotation of the solar magnetic field. A solar disturbance was identified by Pioneer VI as a reversal of the solar magnetospheric field direction which lasted for about one half hour as this solar streamer swept across the Pioneer. Some one hour later, this same streamer swept across Explorer XXVIII as demonstrated by the similarity of the magnetic field perturbation recorded by that spacecraft.

Figure 9

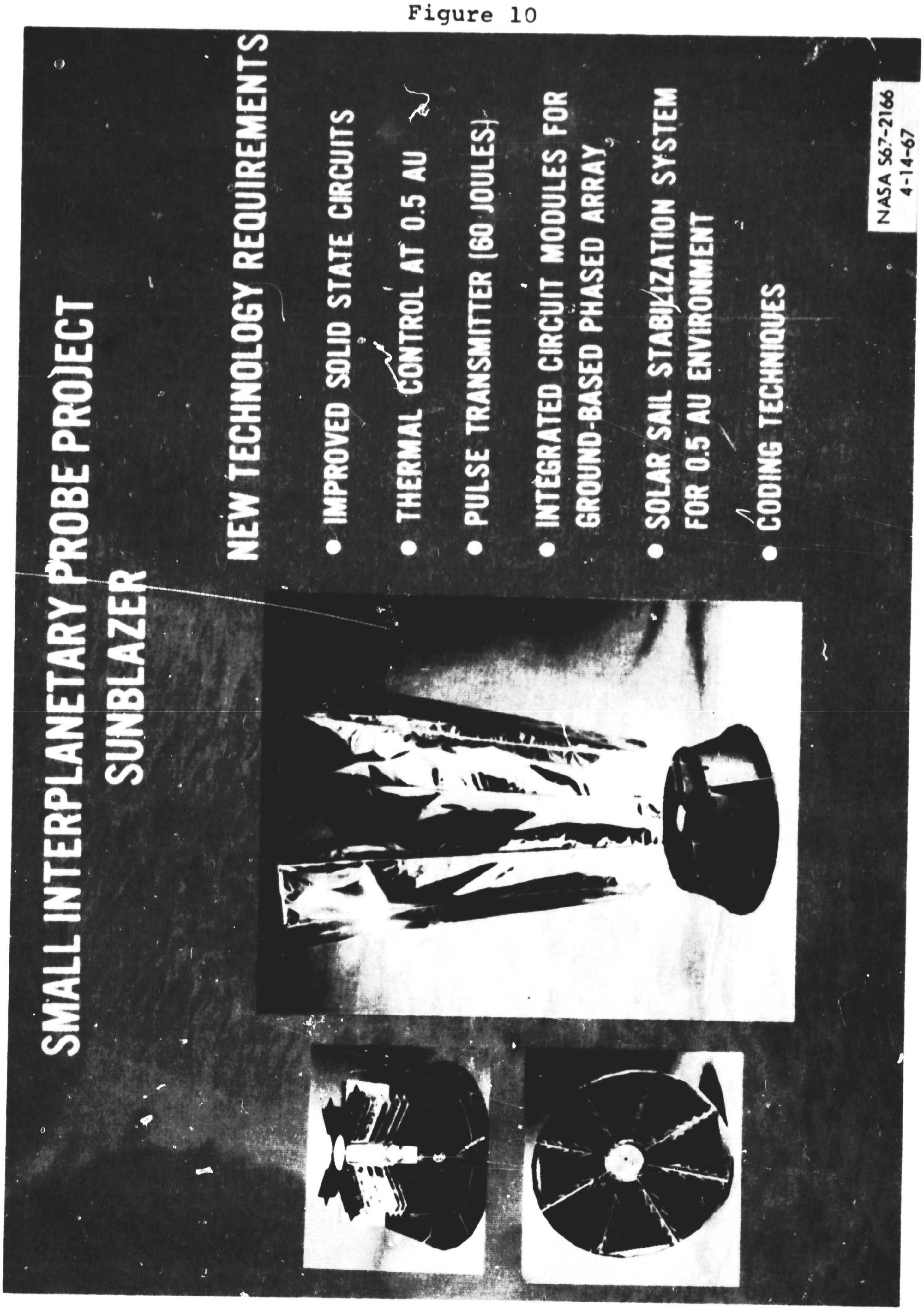


PIONEER AND EXPLORER SHOW SOLAR MAGNETIC FIELD ROTATION
EXPLORER XXVIII
EARTH
LINE 1 HOUR LATER
PIONEER VI
MAGNETIC FIELD LINE
SUN
PIONEER
FIELD DIRECTION
0°
180°
EXPLORER SHIFTED 57.5 MINUTES
02
03
04
05
UT-HOURS-12/22/65
NASA SG 67-849
REV. 3-3-67

SMALL INTERPLANETARY PROBE PROJECT - SUNBLAZER
(Fig. 10)

The Pioneer *in situ* investigation of solar corona is being supplemented by the Sunblazer solar satellite proposed by Massachusetts Institute of Technology. These small probes will be launched with a 5-stage Scout into orbits approaching .5 AU. Although the Sunblazer is expected to weigh in the neighborhood of 25 pounds, it is designed to intermittently transmit a peak power of about 1 kw at 75 MHz and 225 MHz. In a sense, the Sunblazer constitutes an interplanetary sounding rocket which should be applicable to the study of electron density, magnetic field intensity, and plasma flow in the solar corona. This figure summarizes some of the new technology requirements of this type spacecraft.

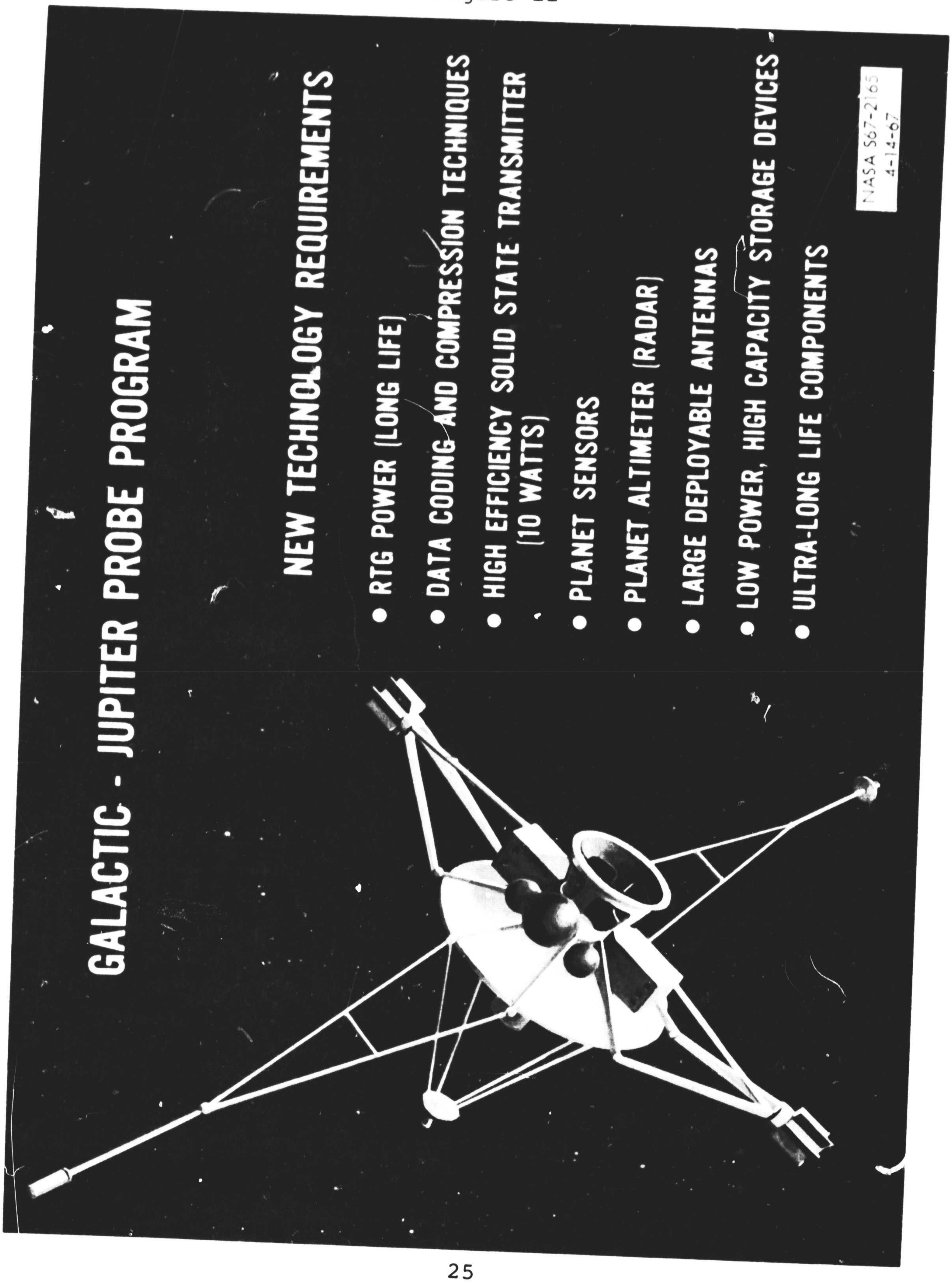
Figure 10


SMALL INTERPLANETARY PROBE PROJECT
SUNBLAZER
NEW TECHNOLOGY REQUIREMENTS
• IMPROVED SOLID STATE CIRCUITS
• THERMAL CONTROL AT 0.5 AU
• PULSE TRANSMITTER (60 JOULES)
• INTEGRATED CIRCUIT MODULES FOR GROUND-BASED PHASED ARRAY
• SOLAR SAIL STABILIZATION SYSTEM FOR 0.5 AU ENVIRONMENT
• CODING TECHNIQUES
NASA S67-2166
4-14-67

GALACTIC-JUPITER PROBE PROGRAM
(Fig. 11)

This program is designed to investigate the solar system far outside the earth's orbit. As a result of the distance from the sun, solar power must be replaced by radioisotope thermoelectric generators (RTG's). In addition to extending particle and field measurements to the outer reaches of the solar system, perhaps to where the galactic field predominates, this probe will be designed to fly close to the planet Jupiter for preliminary observation of that planet. By using the immense gravitational field of Jupiter, such a probe can be diverted to any place in the solar system, including flights directly into the sun, flights over the solar poles, and even flights escaping the solar system. These technological advances will be required.

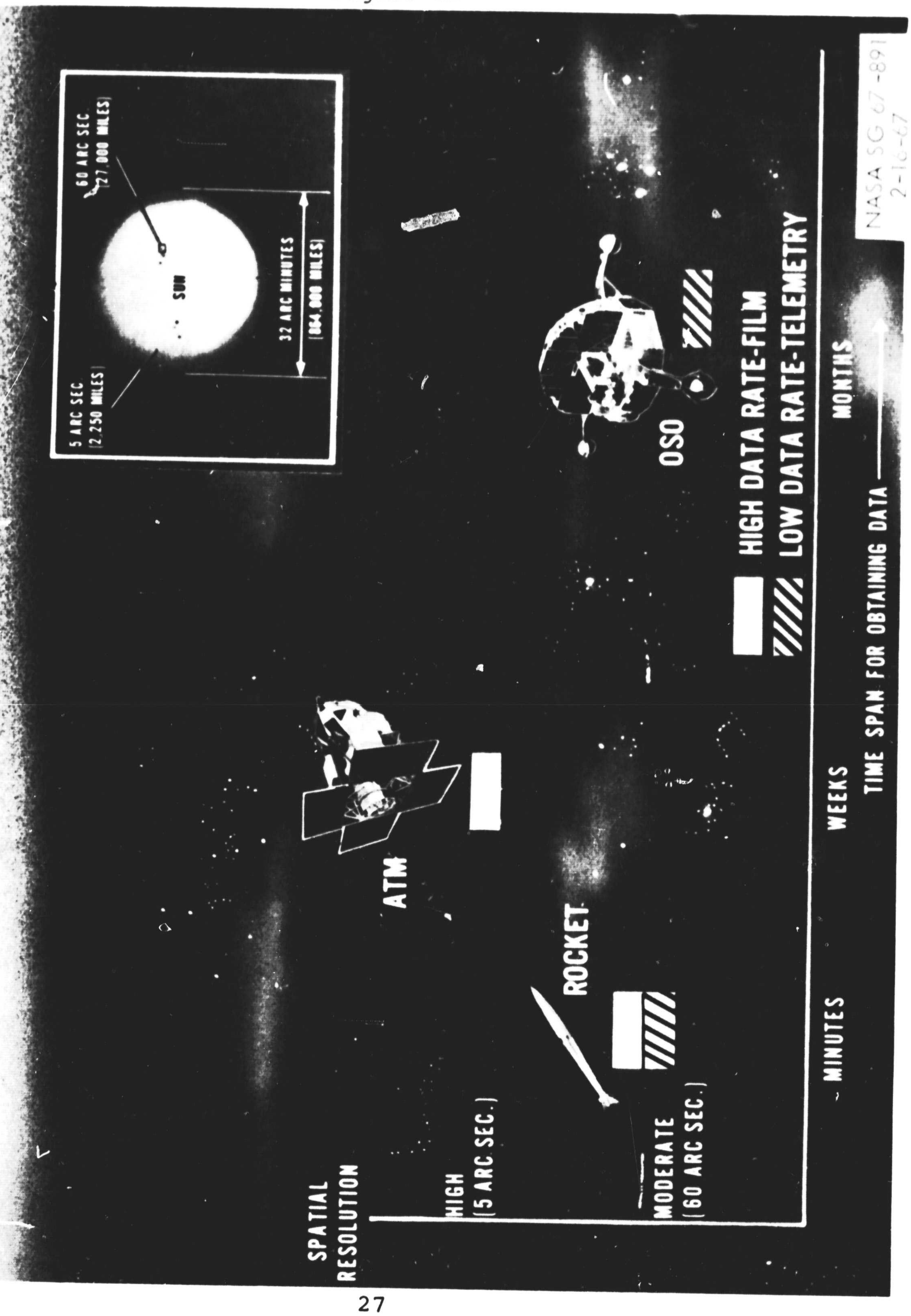
Figure 11


GALACTIC - JUPITER PROBE PROGRAM
NEW TECHNOLOGY REQUIREMENTS
• RTG POWER (LONG LIFE)
• DATA CODING AND COMPRESSION TECHNIQUES
• HIGH EFFICIENCY SOLID STATE TRANSMITTER (10 WATTS)
• PLANET SENSORS
• PLANET ALTIMETER (RADAR)
• LARGE DEPLOYABLE ANTENNAS
• LOW POWER, HIGH CAPACITY STORAGE DEVICES
• ULTRA-LONG LIFE COMPONENTS
NASA S67-2165
4-14-67

CAPABILITIES OF SOLAR SPACECRAFT
(Fig. 12)

In addition to *in situ* measurements in interplanetary space, the sun may be studied in the more classical manner of direct astronomical observations. By making these observations from space, the obscuration of certain spectral regions by the earth's atmosphere is eliminated. Solar observations from space have been made with sounding rockets and three orbiting solar observatories. The OSO's provide moderate resolution for very long periods of time and hence serve the function of monitoring the sun and its disturbances. The OSO's will soon be supplemented with the high resolution instrument array of the Apollo Telescope Mount. Future developments of orbiting solar telescopes will probably be in the direction of still larger semi-automated but man-tended systems which will provide high resolution, long duration and flexible operation.

Figure 12

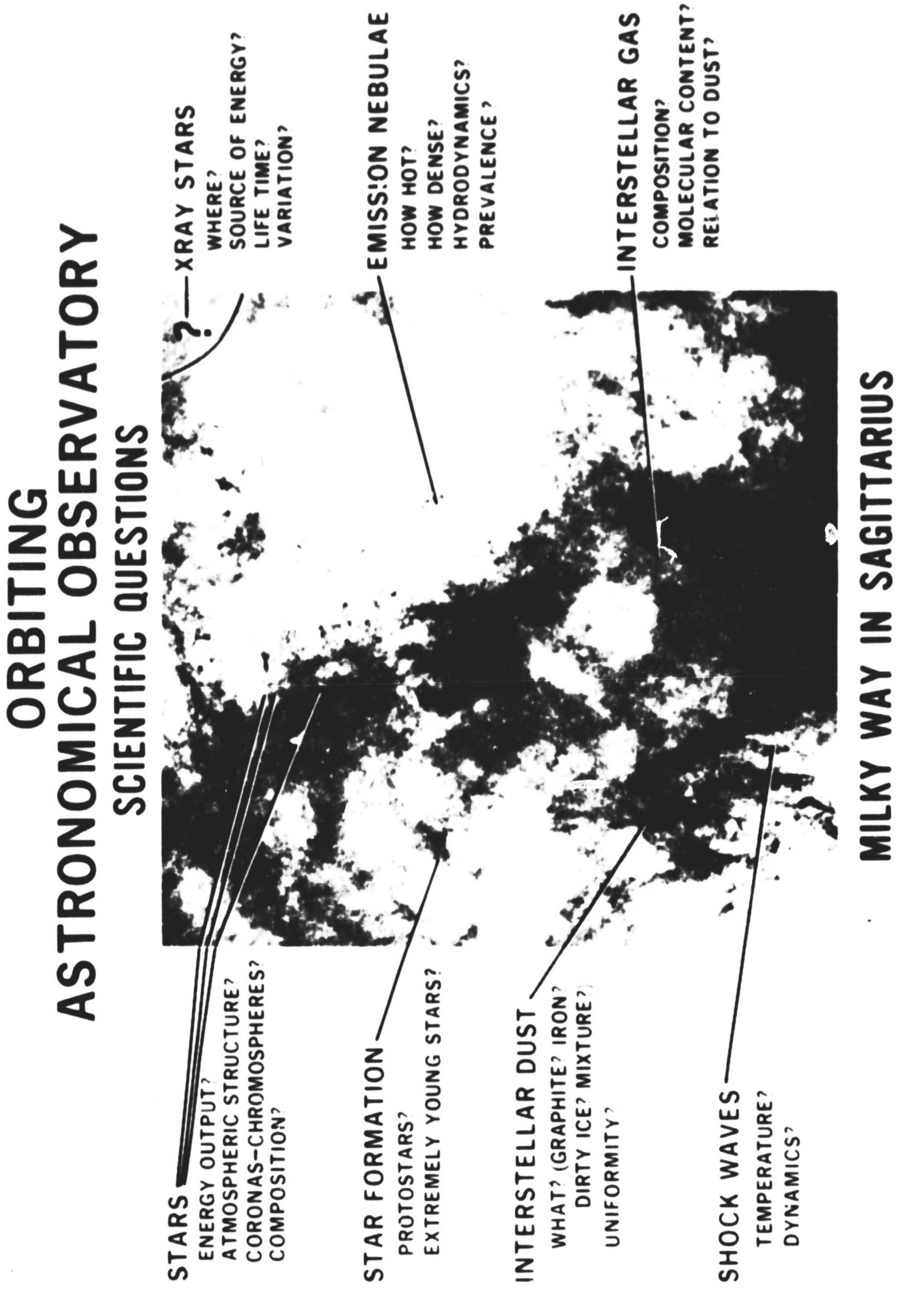

CAPABILITIES OF SOLAR SPACECRAFT
5 ARC SEC. (2,250 MILES)
60 ARC SEC. (27,000 MILES)
SUN
32 ARC MINUTES (864,000 MILES)
SPATIAL RESOLUTION
HIGH (5 ARC SEC.)
MODERATE (60 ARC SEC.)
ROCKET
ATM
OSO
HIGH DATA RATE-FILM
LOW DATA RATE-TELEMETRY
MINUTES
WEEKS
MONTHS
TIME SPAN FOR OBTAINING DATA
NASA SG 67-891
2-16-67

ORBITING ASTRONOMICAL OBSERVATORY - SCIENTIFIC QUESTIONS (Fig. 13)

The last area of Physics and Astronomy to be covered herein is that of stellar astronomy from orbit. This figure summarizes some of the known questions which may be answered with satellite observatories of which the OAO is the first. Beyond the OAO, we anticipate adaption of the Apollo Telescope Mount for stellar observation in the ultraviolet, X-ray, and gamma ray regions. Stellar astronomy of the 1970's is expected to move in the direction of large and versatile semi-automated but man-tended systems. Radio astronomy will be included.

While we are not yet ready to report the results of our studies of the large orbiting astronomical observatories of the future, I can state a firm conviction that such observatories will become a major goal of the space program. The technological requirements will relate to reproducing the qualities of large earth-based observatories in orbit.

Figure 13


ORBITING
ASTRONOMICAL OBSERVATORY
SCIENTIFIC QUESTIONS
STARS
ENERGY OUTPUT?
ATMOSPHERIC STRUCTURE?
CORONAS-CHROMOSPHERES?
COMPOSITION?
STAR FORMATION
PROTOSTARS?
EXTREMELY YOUNG STARS?
INTERSTELLAR DUST
WHAT? (GRAPHITE? IRON? DIRTY ICE? MIXTURE?)
UNIFORMITY?
SHOCK WAVES
TEMPERATURE?
DYNAMICS?
XRAY STARS
WHERE?
SOURCE OF ENERGY?
LIFE TIME?
VARIATION?
EMISSION NEBULAE
HOW HOT?
HOW DENSE?
HYDRODYNAMICS?
PREVALENCE?
INTERSTELLAR GAS
COMPOSITION?
MOLECULAR CONTENT?
RELATION TO DUST?
MILKY WAY IN SAGITTARIUS

SPACE APPLICATIONS
(Fig. 14)

One area of the NASA program which is certain to expand is that of space applications. This program has been one of our most successful efforts. It has yielded operational meteorological, communications, and navigation systems. Furthermore, geodetic satellites are filling a semi-operational role. The economic and social impact of these systems is already being felt and the future operations which have already been identified are even more promising. In fact, it seems probable that the economic benefits derived from satellite applications will some day pay for not only the applications program but a major portion of the entire space program. This figure outlines some of these opportunities. The area of earth resources surveys is the newest application and one of the most exciting. Its development is receiving attention from various agencies in the U. S. government and various nations abroad.

SPACE APPLICATIONS

- **GEODESY**
  - WORLD GEODETIC REFERENCE SYSTEM
  - DEFINE GRAVITY FIELD
- **COMMUNICATIONS & NAVIGATION**
  - POINT-TO-POINT INTERCONTINENTAL
  - SMALL TERMINAL MULTIPLE ACCESS
  - NAVIGATION-TRAFFIC CONTROL
  - DATA RELAY: EARTH - LUNAR - PLANETARY
  - VOICE BROADCAST
  - COMMUNITY TELEVISION
  - TELEVISION BROADCAST
- **METEOROLOGY**
  - DAY & NIGHT CLOUD COVER
  - CONTINUOUS OBSERVATIONS
  - ATMOSPHERIC STRUCTURE FOR LONG RANGE FORECASTS
- **EARTH RESOURCES SURVEY**
  - GEOGRAPHY & CARTOGRAPHY
  - GEOLOGY & MINEROLOGY
  - AGRICULTURE & FORESTRY
  - WATER RESOURCES & POLLUTION CONTROL
  - OCEANOGRAPHY

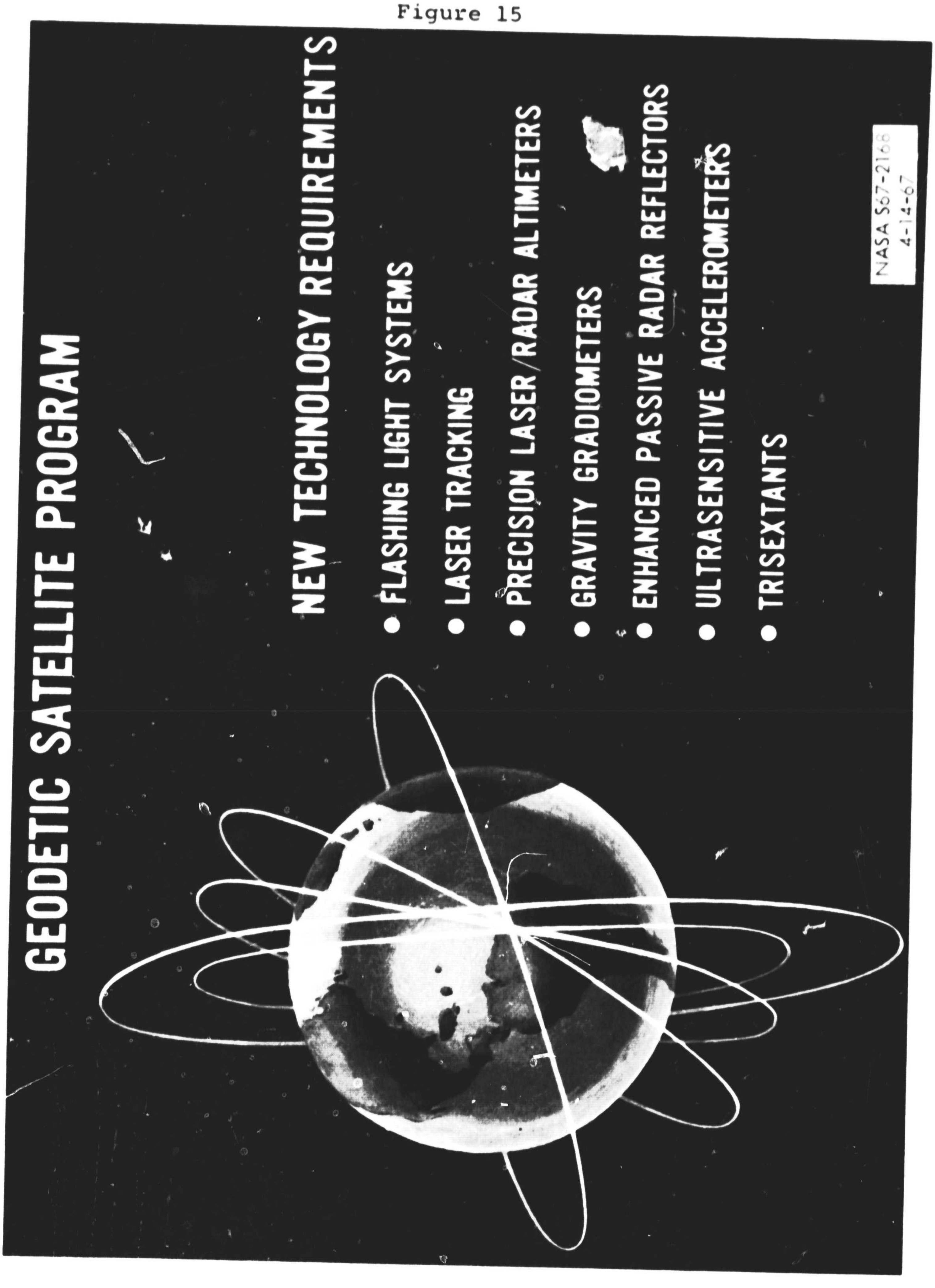
NASA SA 67-2017
2-27-67

Figure 14

GEODETIC SATELLITE PROGRAM
(Fig. 15)

Already geodetic satellites have made dramatic advances in defining the geoid of the earth and in establishing a world-wide network of control points which will ultimately tie together the 14 major and 60 minor geodetic datum systems of the world. Some of the new technology required for advanced geodetic systems is outlined in this figure. Ultimately position accuracies of better than one foot appear possible. Some of the applications of the accurate geodetic information made possible by geodetic satellites are precision location of space tracking systems, precision determination and adjustment of orbits and trajectories, simplified mapping of the uncharted areas of the world, glacier tracking of land motions and continent drift, determination of the ocean surface shape by direct measurement, determination of fault displacement associated with seismic activities, and others.

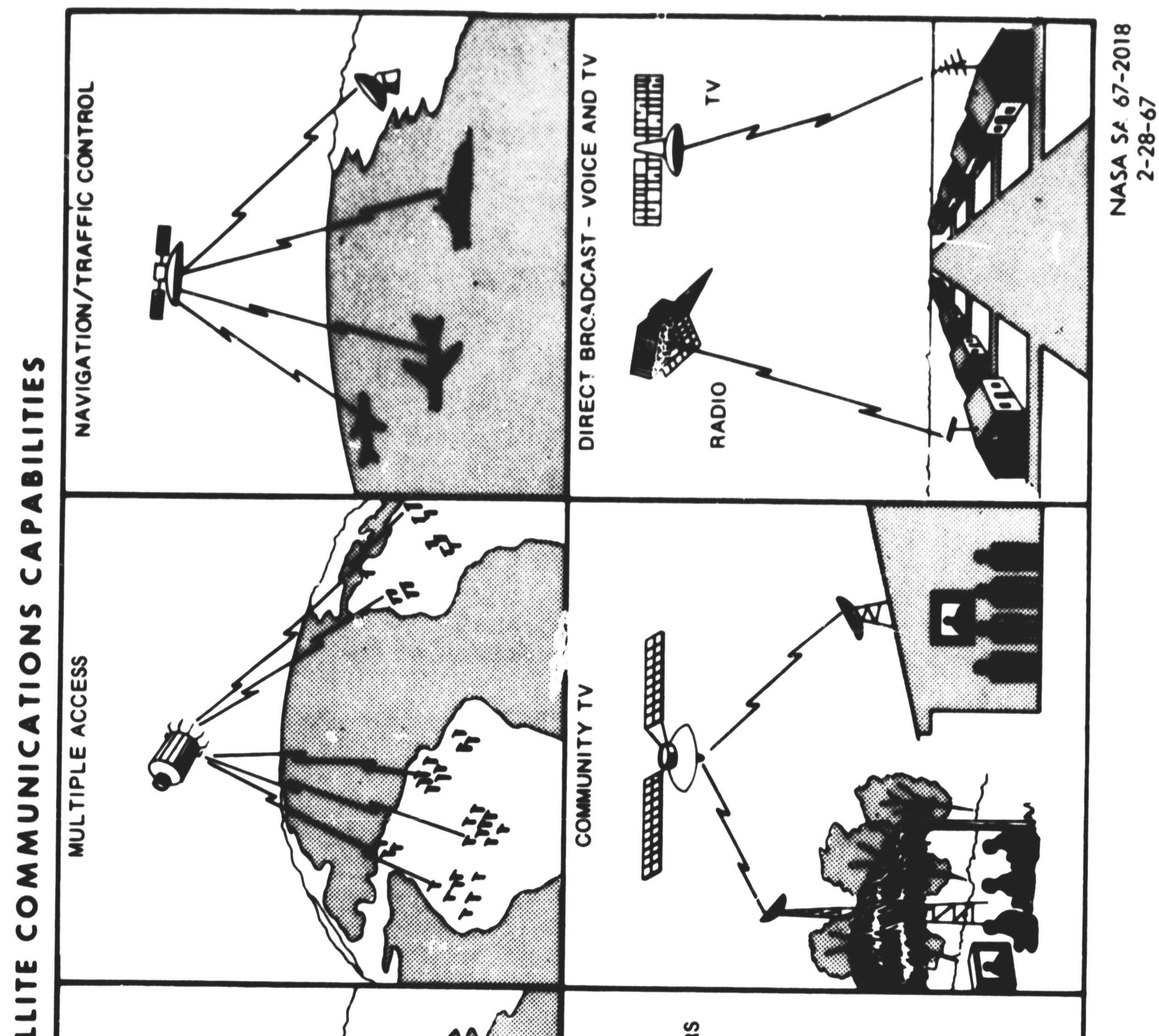
Figure 15


GEODETIC SATELLITE PROGRAM
NEW TECHNOLOGY REQUIREMENTS
• FLASHING LIGHT SYSTEMS
• LASER TRACKING
• PRECISION LASER/RADAR ALTIMETERS
• GRAVITY GRADIOMETERS
• ENHANCED PASSIVE RADAR REFLECTORS
• ULTRASENSITIVE ACCELEROMETERS
• TRISEXTANTS
NASA S67-2168
4-14-67

SATELLITE COMMUNICATIONS CAPABILITIES
(Fig. 16)

Transoceanic television capability is already an operational reality which is operating in the black. Yet this is only the beginning of what will soon become a gigantic step forward in worldwide communications via satellites. Some of the opportunities which lie ahead are shown in this figure. Point to point communications between single large stations will soon be expanded to permit multiple access by many users. The power gain and pointing accuracy of communications satellites will soon permit regular and economical navigation and traffic control of all the aircraft and ships of the world. Satellites with these capabilities can also be used to communicate with other spacecraft in orbit about the earth, the Moon, or the planets. By increasing the power supply of such a satellite, FM radio and television can be broadcast into relatively inexpensive receivers located in small communities all over the world. Still further increases in the power will permit broadcast directly into home sets of current receiving capability. These broadcast satellites will improve the quality and decrease the operating costs of existing distribution systems. They will preclude the necessity of establishing elaborate ground-based distribution systems in the developing nations of the world.

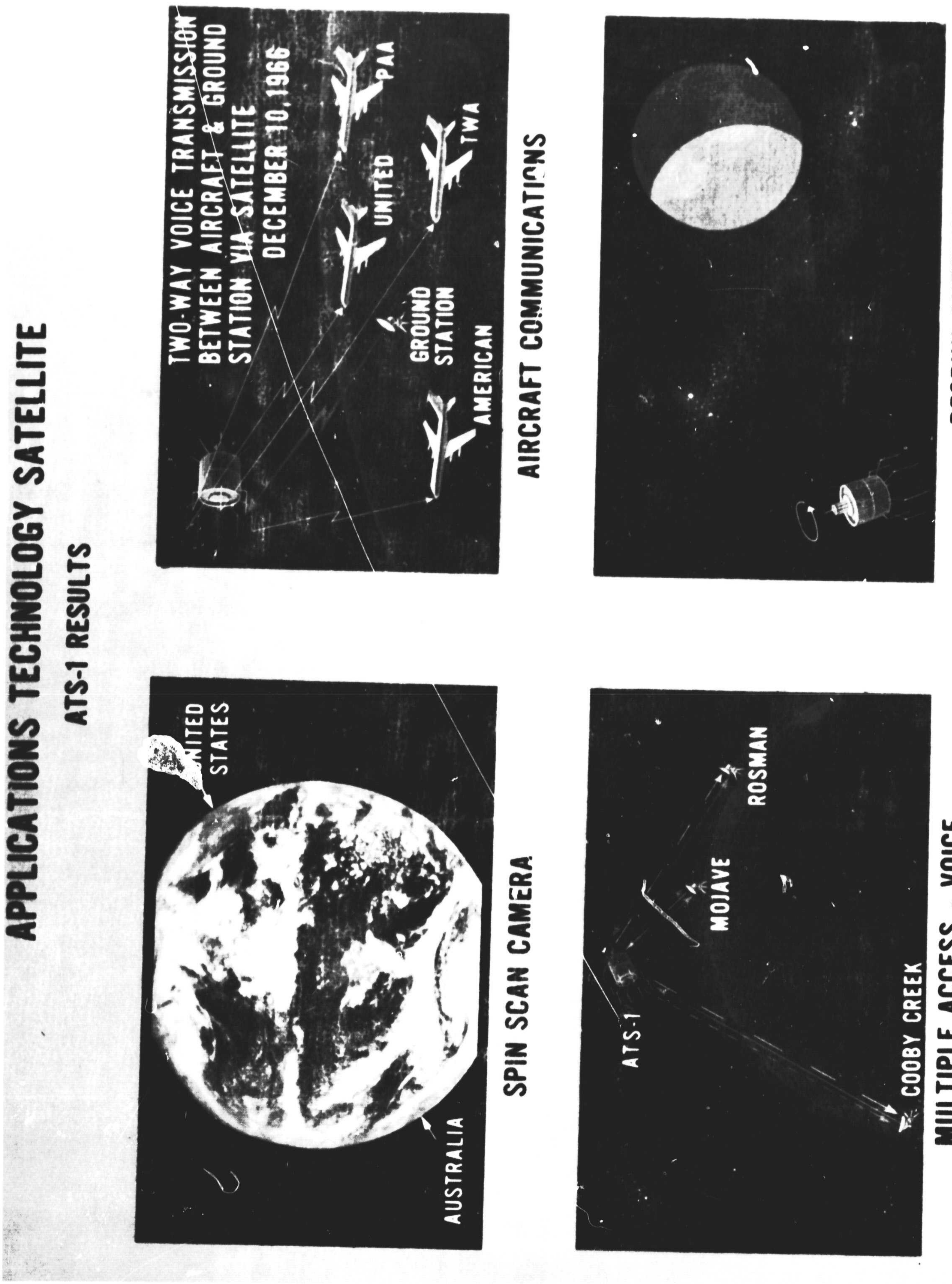
Figure 16


SATELLITE COMMUNICATIONS CAPABILITIES
POINT TO POINT
MULTIPLE ACCESS
NAVIGATION/TRAFFIC CONTROL
DATA RELAYS
MARS
COMMUNITY TV
DIRECT BROADCAST - VOICE AND TV
RADIO
TV
NASA SA 67-2018
2-28-67

APPLICATIONS TECHNOLOGY SATELLITE - ATS-1 RESULTS (Fig. 17)

New applications in meteorology, communications, navigation and traffic control are being pioneered with Applications Technology Satellites. This figure illustrates some of the dramatic accomplishments of the ATS-1 launched late last year. Continuous observation of the entire disk of the earth is possible. Three such satellites with zoom lens capability would permit an operator at a single console at a world weather station to continuously monitor the weather of the entire earth and to study in detail areas of interest or concern. The potential for air traffic control over the increasingly crowded transAtlantic routes has already been demonstrated with crystal clear two-way voice communications between East coast stations and aircraft as far away as the Western Pacific. The airborne equipment is relatively modest even with this simple satellite. Multiple access voice communication has been demonstrated and an electronic despun antenna has provided us with relatively high gain.

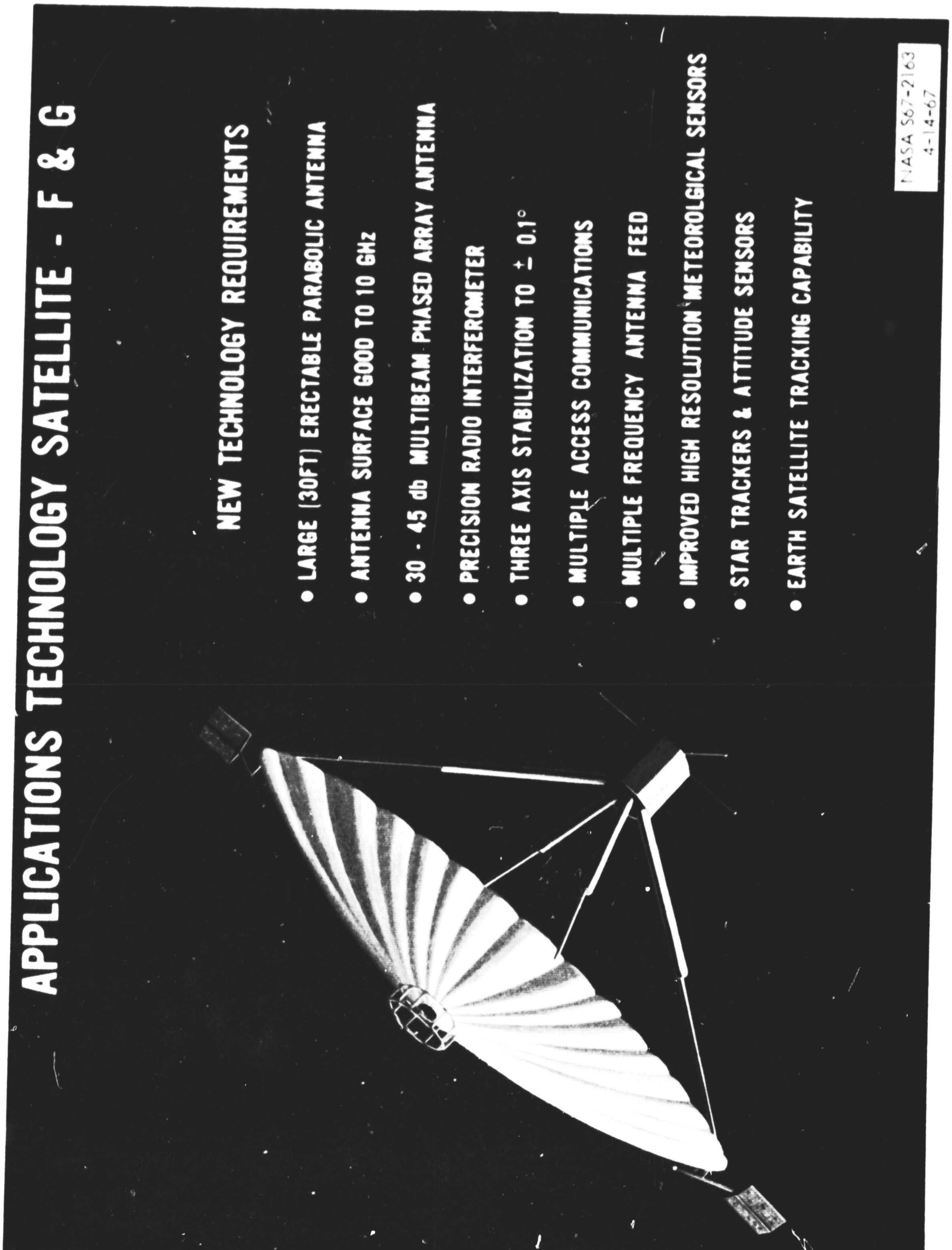
Figure 17


APPLICATIONS TECHNOLOGY SATELLITE
ATS-1 RESULTS
UNITED STATES
AUSTRALIA
SPIN SCAN CAMERA
TWO-WAY VOICE TRANSMISSION BETWEEN AIRCRAFT & GROUND STATION VIA SATELLITE DECEMBER 10, 1966
PAA
UNITED
TWA
GROUND STATION
AMERICAN
AIRCRAFT COMMUNICATIONS
ATS-1
MOJAVE
ROSMAN
COOBY CREEK
MULTIPLE ACCESS - VOICE
DESPUN ANTENNA

APPLICATIONS TECHNOLOGY SATELLITES - F & G
(Fig. 18)

The next step in applications technology satellites is illustrated in this figure. This 30-foot parabolic antenna is good to 10 GHz and will provide precision pointing and high-gain communications. The applications of such a satellite and its technology are many and contribute dramatically to all applications areas which I have already identified. To illustrate the communications potential of this spacecraft, person-to-person communications with back-pack transmitter and receiver systems would be possible via this satellite. From this technology will evolve the operational satellites of the 1970's.

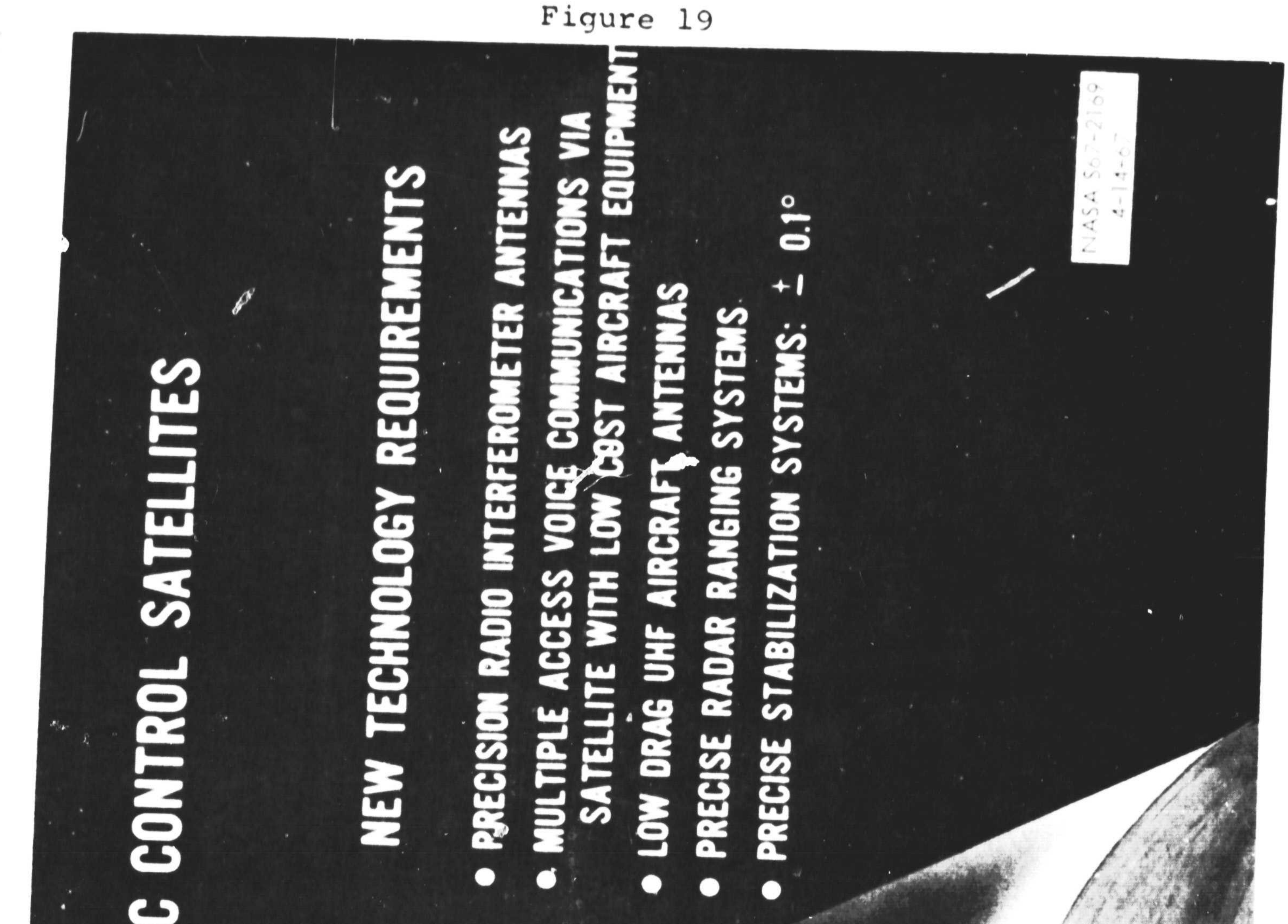
Figure 18


APPLICATIONS TECHNOLOGY SATELLITE - F & G
NEW TECHNOLOGY REQUIREMENTS
• LARGE (30FT) ERECTABLE PARABOLIC ANTENNA
• ANTENNA SURFACE GOOD TO 10 GHz
• 30 - 45 db MULTIBEAM PHASED ARRAY ANTENNA
• PRECISION RADIO INTERFEROMETER
• THREE AXIS STABILIZATION TO ± 0.1°
• MULTIPLE ACCESS COMMUNICATIONS
• MULTIPLE FREQUENCY ANTENNA FEED
• IMPROVED HIGH RESOLUTION METEOROLGICAL SENSORS
• STAR TRACKERS & ATTITUDE SENSORS
• EARTH SATELLITE TRACKING CAPABILITY
NASA S67-2163
4-14-67

NAVIGATION/TRAFFIC CONTROL SATELLITES
(Fig. 19)

Although it is quite likely that satellites of the Applications Technology Satellites F & G configuration may be applied to the navigation and traffic control role, even simpler satellites can suffice. Some of the technology required for these systems is indicated in this figure. These techniques will permit continuous all-weather navigation and communications capability over the entire globe. Navigation accuracies of a mile or better are achievable. Not only will these systems contribute to flight safety, but in the event of an accident, they will provide instant detection and location of distress signals. The traffic control potential will make possible sizeable cost savings through more efficient operations.

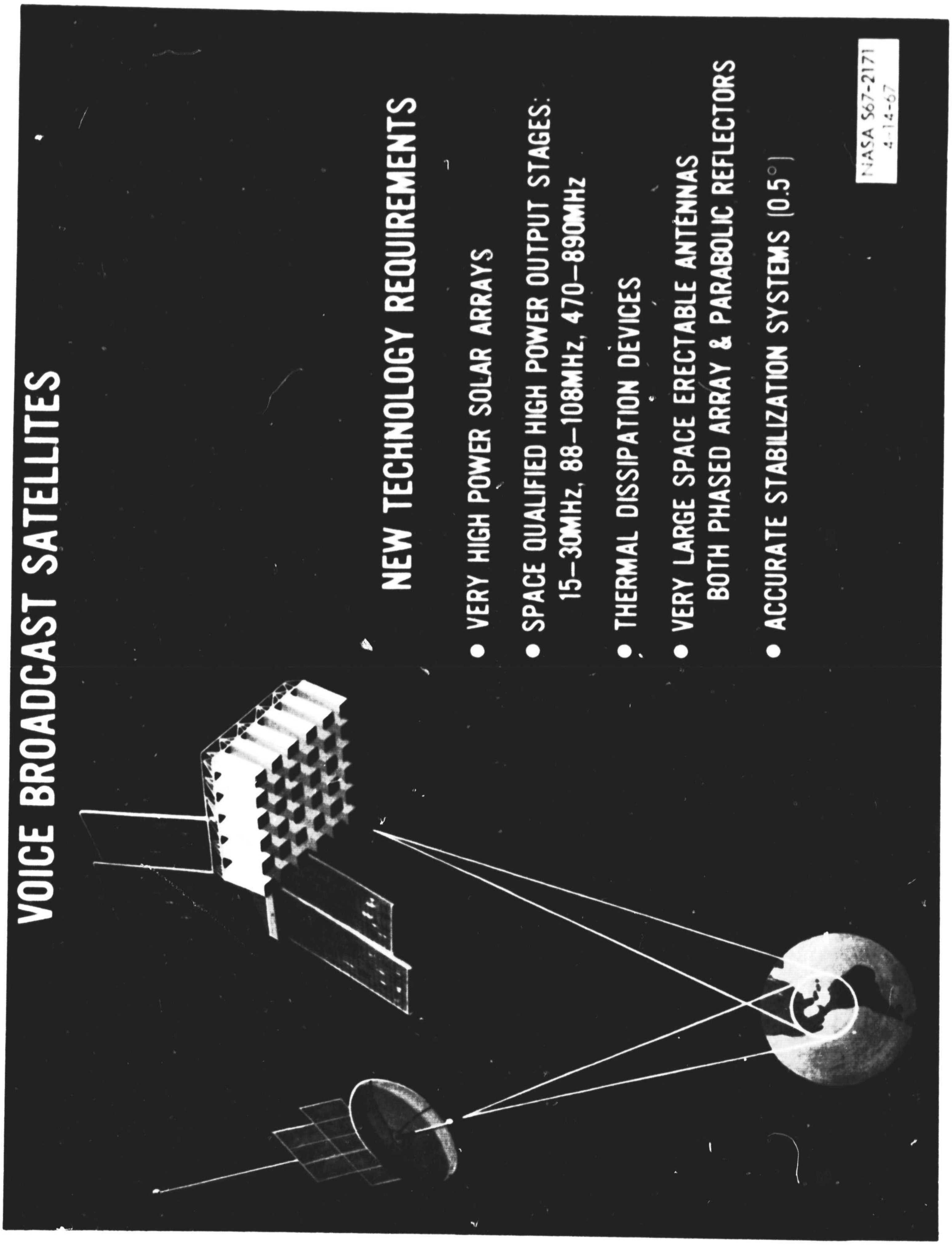
Figure 19


NAVIGATION/TRAFFIC CONTROL SATELLITES
NEW TECHNOLOGY REQUIREMENTS
• PRECISION RADIO INTERFEROMETER ANTENNAS
• MULTIPLE ACCESS VOICE COMMUNICATIONS VIA SATELLITE WITH LOW COST AIRCRAFT EQUIPMENT
• LOW DRAG UHF AIRCRAFT ANTENNAS
• PRECISE RADAR RANGING SYSTEMS
• PRECISE STABILIZATION SYSTEMS: ± 0.1°
NASA S67-2169
4-14-67

VOICE BROADCAST SATELLITES
(Fig. 20)

The problems of voice broadcast satellites are somewhat different from television broadcast unless the voice broadcast is in the ultra high frequency range. For the next decade or so, there will be far more radio sets around the world than television sets. Should direct communication with these sets be desired, lower frequencies, higher powers, and large antennas will be required. The motivation to expand this capability lies in the short range line of sight limitation on FM transmission and the uncertain quality of regular and short wave AM transmission. A large fraction of the world's people can be reached at these frequencies for educational, cultural, and informational purposes.

Figure 20

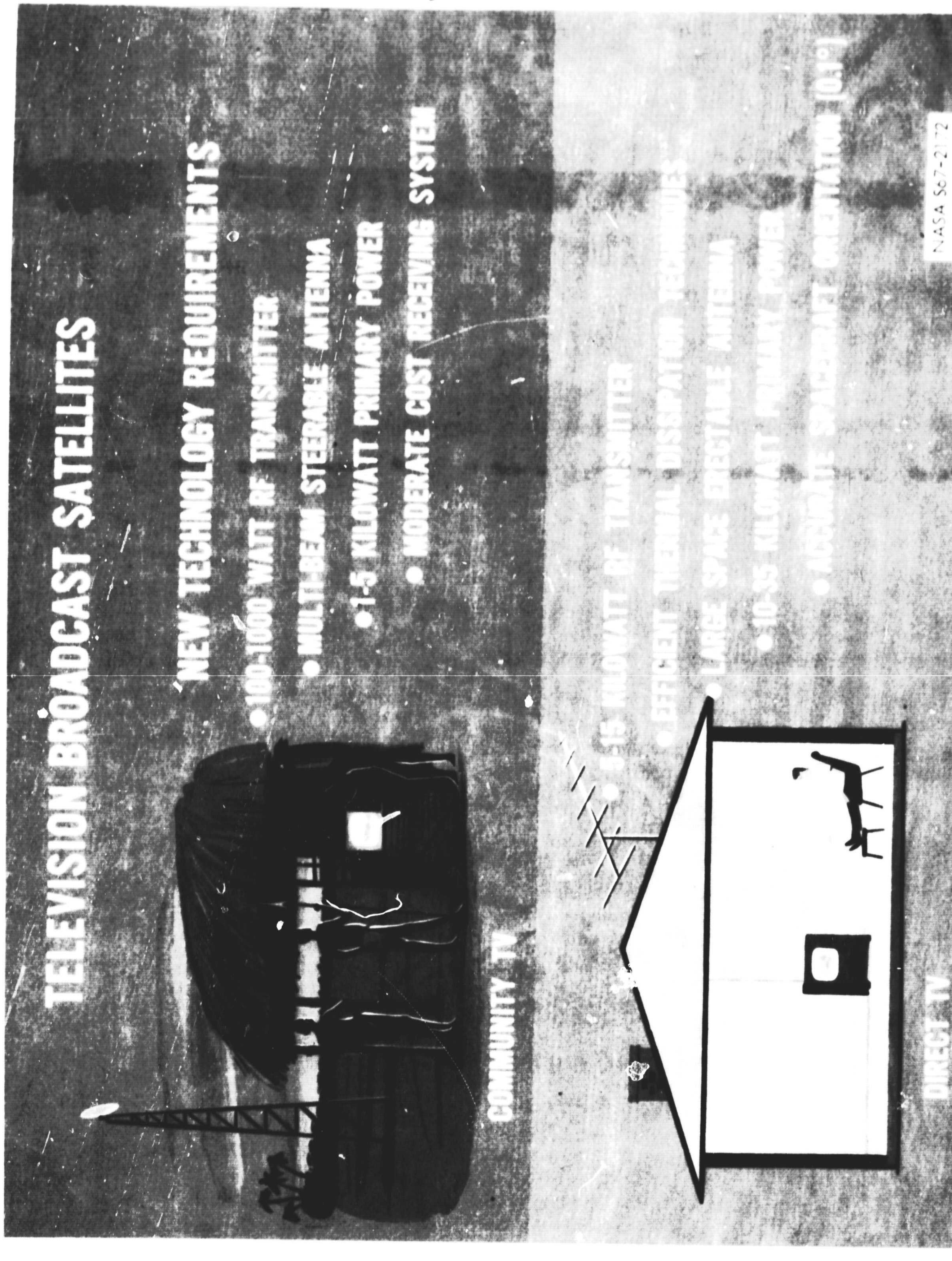


VOICE BROADCAST SATELLITES
NEW TECHNOLOGY REQUIREMENTS
• VERY HIGH POWER SOLAR ARRAYS
• SPACE QUALIFIED HIGH POWER OUTPUT STAGES: 15–30MHz, 88–108MHz, 470–890MHz
• THERMAL DISSIPATION DEVICES
• VERY LARGE SPACE ERECTABLE ANTENNAS BOTH PHASED ARRAY & PARABOLIC REFLECTORS
• ACCURATE STABILIZATION SYSTEMS (0.5°)
NASA S67-2171
4-14-67

TV BROADCAST SATELLITES
(Fig. 21)

I have already introduced the concept of direct broadcast of television into the home via satellites and have mentioned some of the technology required. This figure further elaborates on the technological advancements required for both the broadcast of community TV and direct TV into the home. It seems highly likely that this technique will replace current distribution techniques within the next ten or fifteen years and perhaps sooner, not only for developing nations but for countries, such as the United States, which already have elaborate earth based distribution systems. The satellite system should more than pay for itself in reduced cost of operations.

Figure 21


TELEVISION BROADCAST SATELLITES
NEW TECHNOLOGY REQUIREMENTS
• 100-1000 WATT RF TRANSMITTER
• MULTI-BEAM STEERABLE ANTENNA
• 1-5 KILOWATT PRIMARY POWER
• MODERATE COST RECEIVING SYSTEM
COMMUNITY TV
• 5-15 KILOWATT RF TRANSMITTER
• EFFICIENT THERMAL DISSIPATION TECHNIQUES
• LARGE SPACE ERECTABLE ANTENNA
• 10-35 KILOWATT PRIMARY POWER
• ACCURATE SPACECRAFT ORIENTATION (0.1°)
DIRECT TV
NASA S67-2172
4-14-67

SATELLITE CONTRIBUTIONS TO WEATHER PREDICTION
(Fig. 22)

Since the beginning of the space program, it has been recognized that the earth satellite offers the meteorologist his only hope of obtaining continuous global observations of the atmospheric parameters required to permit long-range weather prediction. This figure illustrates the nature of the problem. For short-term, high-intensity storms of from one to ten miles in size and from one to ten hours in duration, continuous observation is required. This observation of tornado and thunderstorm systems can best be accomplished by weather satellites at the synchronous altitudes. These satellites can also observe some properties of very large atmospheric disturbances including hurricanes, cyclones, and global waves ranging from 100 to 10,000 miles in size. It is these larger disturbances which must be analyzed to permit predictions of up to two weeks. However, these long-range predictions require measurement on a fairly tight global grid of pressure, temperature, density, humidity, wind velocity, and radiative flux. These detailed measurements can best be obtained in the foreseeable future from low altitude satellites. Current operational systems have enhanced the three-day predictions. Future operational systems with improved sensors should extend the forecast capability to about two weeks with projected annual savings of several billion dollars to farmers, manufacturers, construction companies, resort operators, entrepeneurs of all types, and even individua

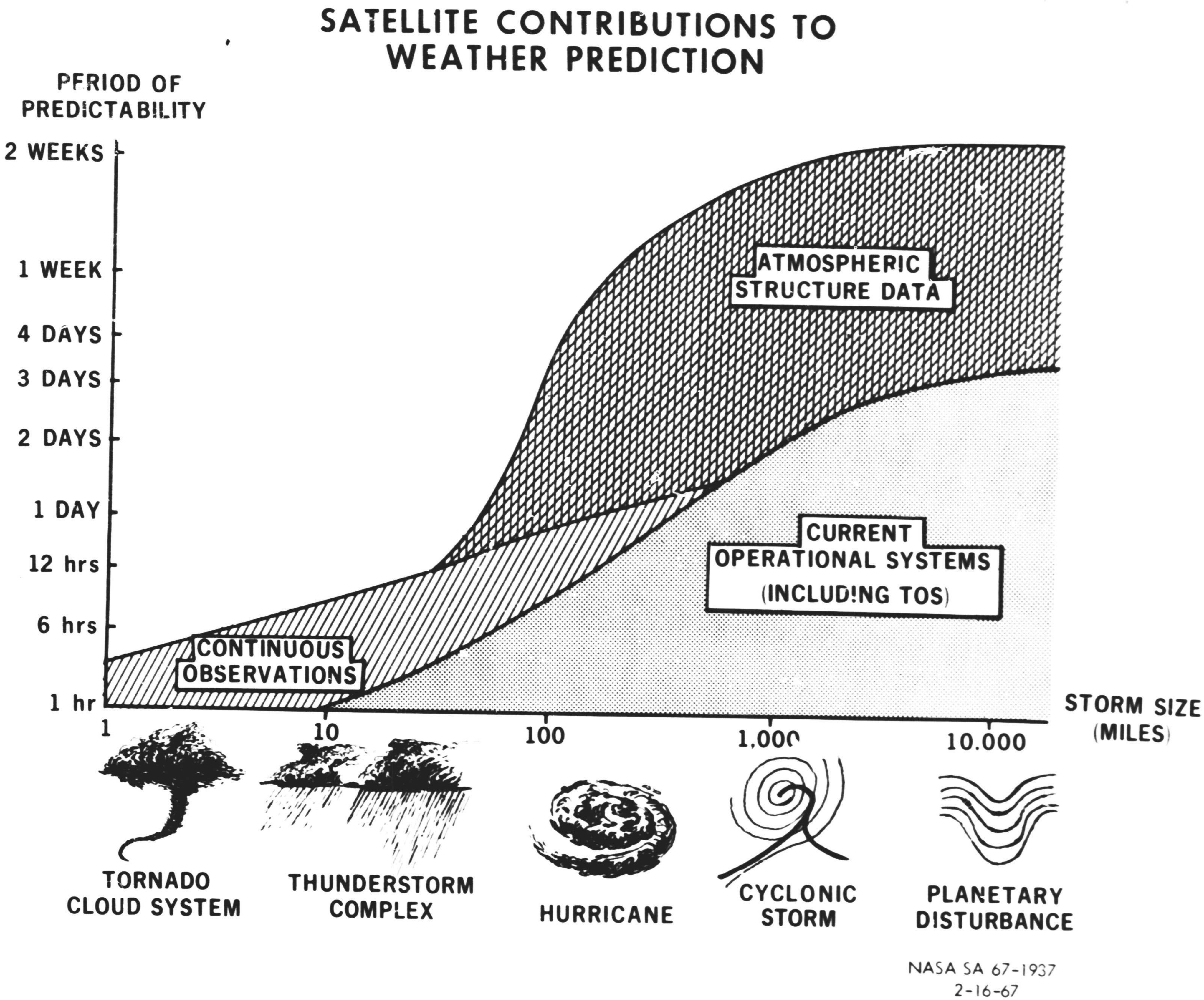
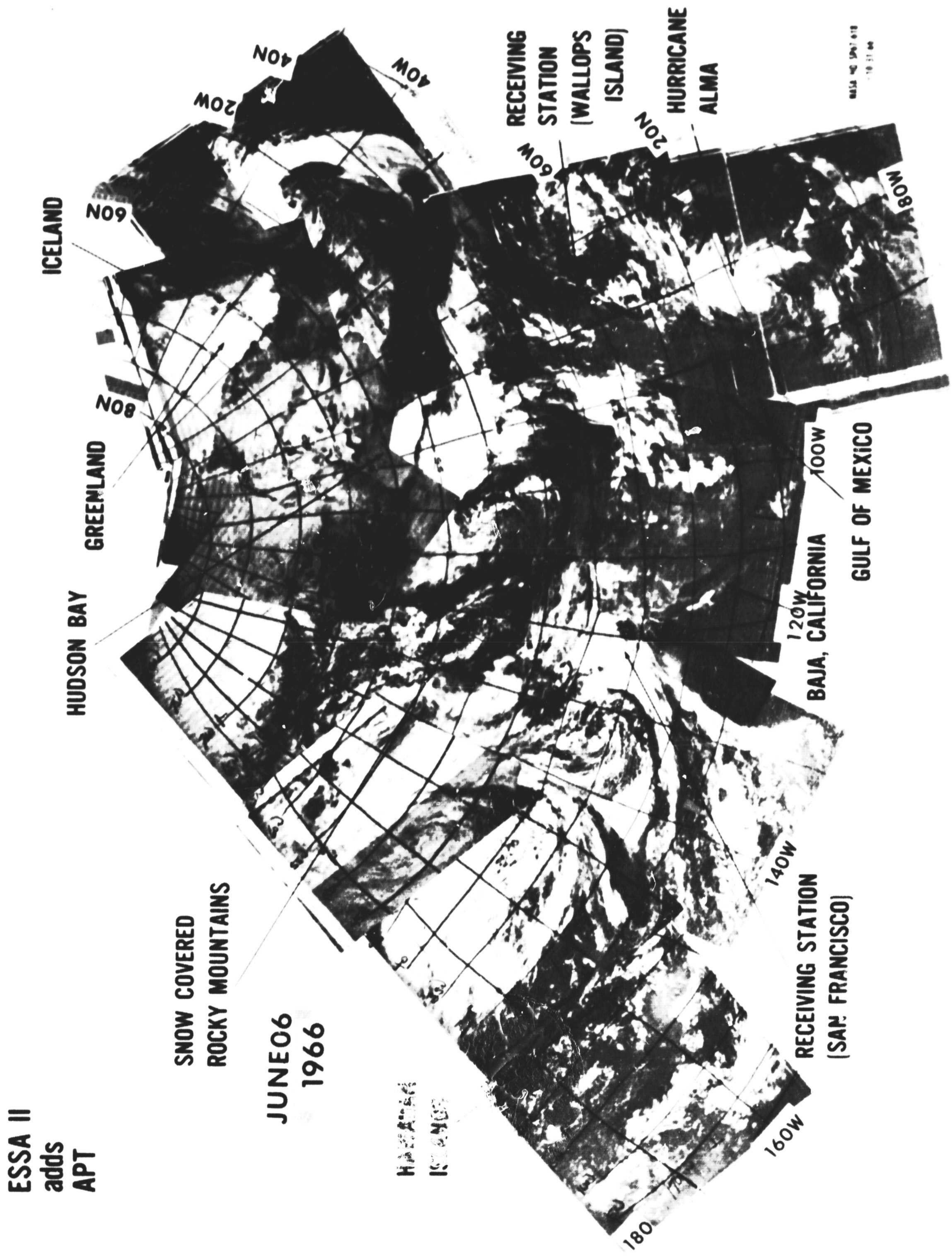

SATELLITE CONTRIBUTIONS TO
WEATHER PREDICTION
PERIOD OF
PREDICTABILITY
2 WEEKS
1 WEEK
4 DAYS
3 DAYS
2 DAYS
1 DAY
12 hrs
6 hrs
1 hr
ATMOSPHERIC
STRUCTURE DATA
CURRENT
OPERATIONAL SYSTEMS
(INCLUDING TOS)
CONTINUOUS
OBSERVATIONS
1
10
100
1,000
10.000
STORM SIZE
(MILES)
TORNADO
CLOUD SYSTEM
THUNDERSTORM
COMPLEX
HURRICANE
CYCLONIC
STORM
PLANETARY
DISTURBANCE
NASA SA 67-1937
2-16-67

Figure 22

ESSA II ADDS APT
(Fig. 23)

Our current operational weather satellite system makes use of two satellites: one to broadcast continuously the view beneath it, and one to store the cloud photographs for reproduction within the United States. The automatic picture transmission is received by more than 150 inexpensive stations around the world. Two such stations located on the east and west coasts of the United States daily obtain the dramatic coverage shown in this figure, which spans over 8,000 miles from east of Iceland to west of Hawaii.

Figure 23

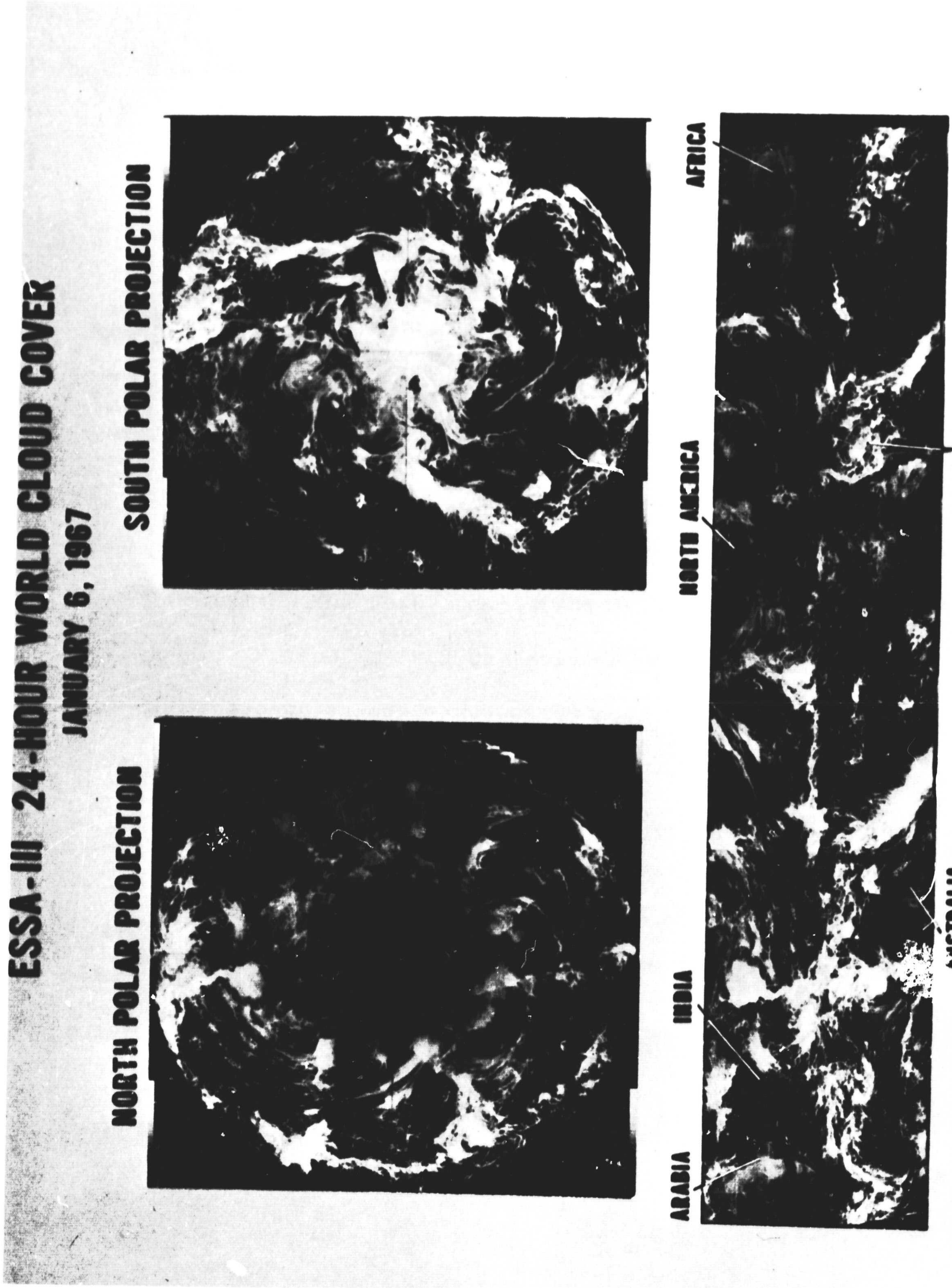

ESSA II
adds
APT
JUNE06
1966
SNOW COVERED
ROCKY MOUNTAINS
HUDSON BAY
GREENLAND
80N
ICELAND
60N
20W
40N
40W
RECEIVING
STATION
(WALLOPS
ISLAND)
60W
20N
HURRICANE
ALMA
80W
100W
GULF OF MEXICO
120W
BAJA, CALIFORNIA
140W
RECEIVING STATION
(SAN FRANCISCO)
160W
180

ESSA III 24-HOUR WORLD CLOUD COVER, JANUARY 6, 1967
(Fig. 24)

This figure illustrates the current capability of the ESSA satellites to collect global cloud data on a daily basis. Such information is being simplified in information content by ESSA and transmitted on a global basis each day. It is being used routinely by operators of both military and civilian aircraft.

The Soviet Union is cooperating in the collection and exchange of satellite weather data. Weather prediction is a common problem to all the peoples of the world and has long enjoyed an atmosphere of international cooperation.

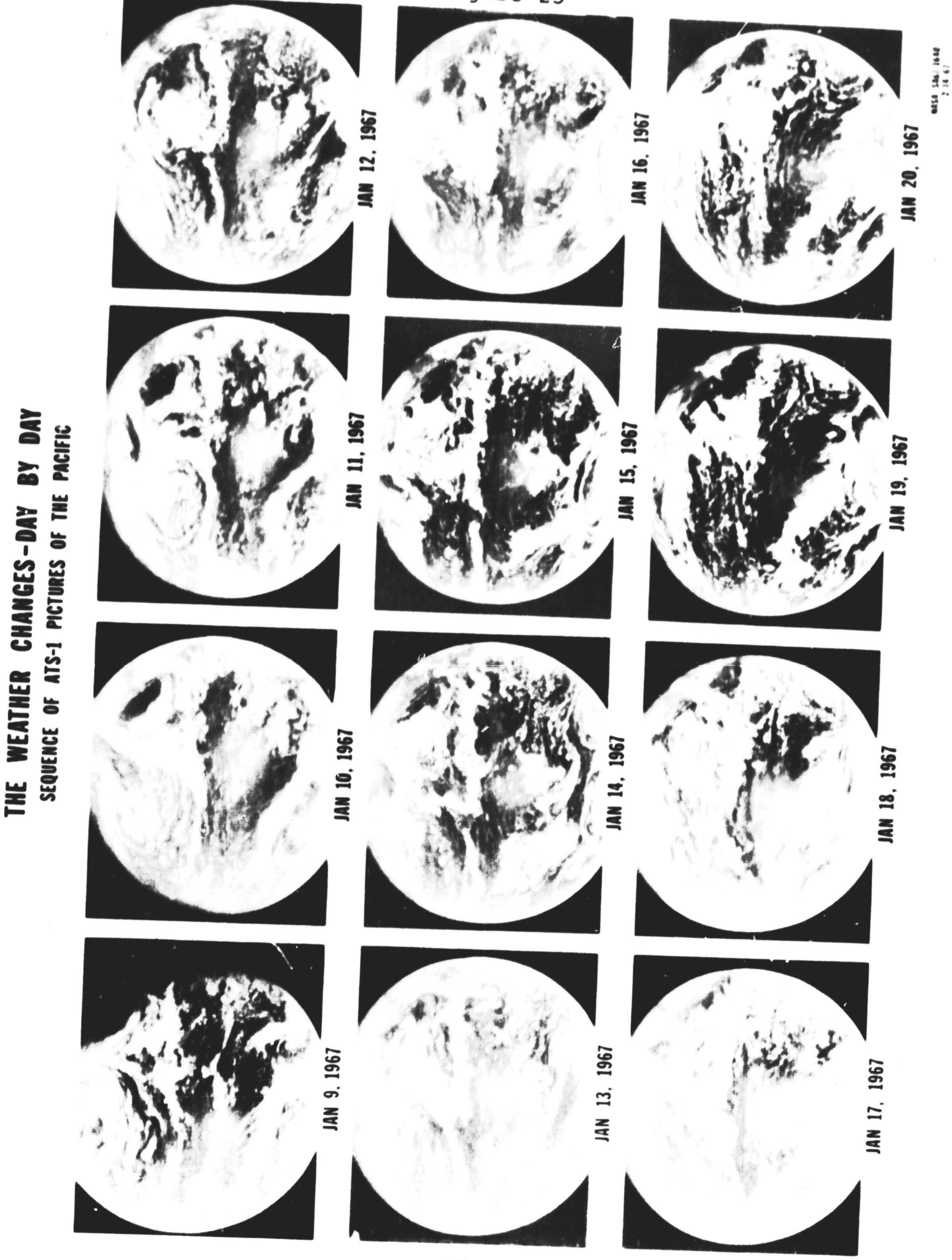
Figure 24


ESSA-III 24-HOUR WORLD CLOUD COVER
JANUARY 6, 1967
NORTH POLAR PROJECTION
SOUTH POLAR PROJECTION
ARABIA
INDIA
AUSTRALIA
NORTH AMERICA
SOUTH AMERICA
AFRICA
MID LATITUDES
NASA S67-1639
2-1-67

THE WEATHER CHANGES - DAY BY DAY
(Fig. 25)

The tremendous advantage of the synchronous orbit for simple cloud cover data collection operations is illustrated in this figure which shows a 12-day sequence of the weather over the entire Pacific from the Americas to the Far East. Time-lapse films of such photographs are being prepared to study the dynamics of the global atmosphere over a period of months.

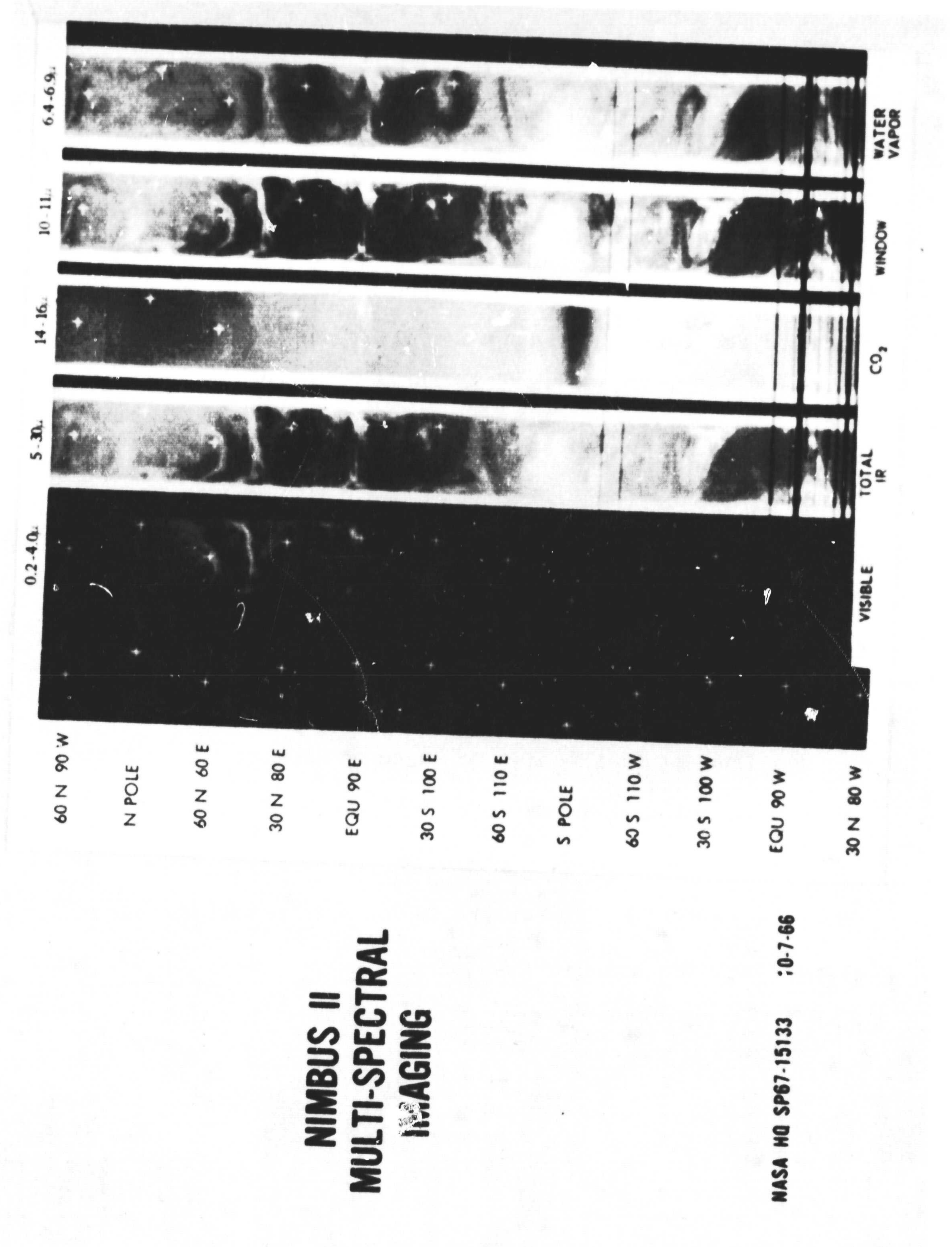
Figure 25


THE WEATHER CHANGES—DAY BY DAY
SEQUENCE OF ATS-1 PICTURES OF THE PACIFIC
JAN 9, 1967
JAN 10, 1967
JAN 11, 1967
JAN 12, 1967
JAN 13, 1967
JAN 14, 1967
JAN 15, 1967
JAN 16, 1967
JAN 17, 1967
JAN 18, 1967
JAN 19, 1967
JAN 20, 1967

NIMBUS II MULTI-SPECTRAL IMAGING
(Fig. 26)

The advantages of the lower orbit satellites are illustrated by this figure, although, as a matter of fact, this infrared imaging is adaptable to synchronous orbits. The MRIR system views the earth in the five indicated wavelengths. The strips are each 2,000 miles wide and circle the globe from pole to pole. Notice the subcontinent of India at 30°N 80°E. The Nimbus satellite has been used to develop all of the new detectors which have been fed into the operational meteorological satellite system. The Nimbus II has demonstrated its ability to function under full earth-pointing attitude control for at least one year.

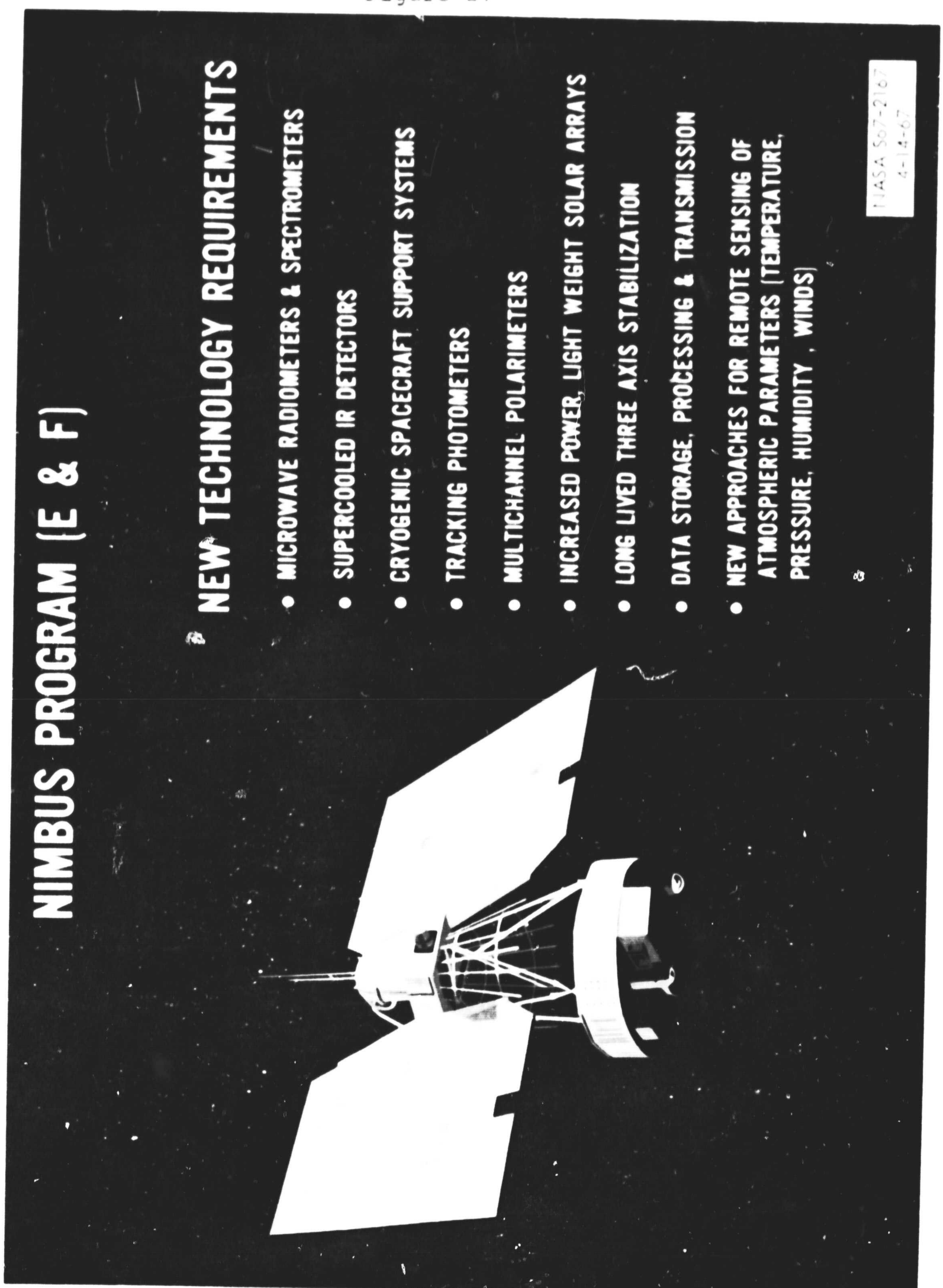
Figure 26


NIMBUS II
MULTI-SPECTRAL
IMAGING
NASA HQ SP67-15133 10-7-66
0.2-4.0μ
VISIBLE
5-30μ
TOTAL IR
14-16μ
CO_2
10-11μ
WINDOW
6.4-6.9μ
WATER VAPOR
60 N 90 W
N POLE
60 N 60 E
30 N 80 E
EQU 90 E
30 S 100 E
60 S 110 E
S POLE
60 S 110 W
30 S 100 W
EQU 90 W
30 N 80 W

NIMBUS PROGRAM (E & F)
(Fig. 27)

The new sensors and techniques required to obtain the global data required for long-range weather forecasting place heavy demands on the research and development spacecraft of the future. There is a clear need for more weight, more power, and the ability to carry many detectors simultaneously. It appears that a relatively modest upgrading of the Nimbus system will suffice for this purpose for perhaps another decade. The follow-on Nimbus configuration shown here involves the simplified and improved attitude control system and a larger solar array. It is otherwise similar to the current Nimbus spacecraft. The new technology required is in the area of sensors to measure indirectly atmospheric parameters or to collect data from balloons and surface stations around the globe. These technologies are exceedingly difficult, but the tremendous potential associated with success dictates an intensive effort to develop them.

Figure 27


NIMBUS PROGRAM (E & F)
NEW TECHNOLOGY REQUIREMENTS
• MICROWAVE RADIOMETERS & SPECTROMETERS
• SUPERCOOLED IR DETECTORS
• CRYOGENIC SPACECRAFT SUPPORT SYSTEMS
• TRACKING PHOTOMETERS
• MULTICHANNEL POLARIMETERS
• INCREASED POWER, LIGHT WEIGHT SOLAR ARRAYS
• LONG LIVED THREE AXIS STABILIZATION
• DATA STORAGE, PROCESSING & TRANSMISSION
• NEW APPROACHES FOR REMOTE SENSING OF ATMOSPHERIC PARAMETERS (TEMPERATURE, PRESSURE, HUMIDITY, WINDS)
NASA S67-2167
4-14-67

SYNCHRONOUS METEOROLOGICAL SATELLITE PROGRAM
(Fig. 23)

The Applications Technology Satellite has demonstrated the potential of synchronous meteorological satellites sufficiently well that the pressures to enhance the operational system with synchronous satellites are mounting. To make such a system yield its maximum potential at an early date requires the technological advances indicated in this figure.

Figure 28

EARTH RESOURCES SURVEY PROGRAM - APPLICATIONS (Fig. 29)

The last applications area which I will discuss is that of earth resources survey. This figure lists the areas of potential applicability of such a survey and is self-explanatory. Although the techniques of data collection, analysis, and application remain to be developed in the years ahead, there is widespread agreement that the potential is tremendous. With the expanding world population, it seems self-evident that monitoring and management of the earth's resources will become essential and that centralized efforts will be required to optimize the effective preservation and utilization of these resources.

Figure 29

EARTH RESOURCES SURVEY PROGRAM

APPLICATIONS

AGRICULTURE AND FORESTRY PRODUCTION

TO AID IN THE INCREASE OF AGRICULTURE AND FOREST PRODUCTION

GEOGRAPHY, CARTOGRAPHY, CULTURAL RESOURCES

TO PERMIT BETTER USE OF RURAL AND METROPOLITAN LAND AREAS AND TO UPDATE TOPOGRAPHIC BASE MAPS AND CENSUS INVENTORIES

GEOLOGY AND MINERAL RESOURCES

TO AID IN THE DISCOVERY AND EXPLOITATION OF MINERAL AND PETROLEUM RESOURCES

HYDROLOGY AND WATER RESOURCES

TO AID IN THE LOCATION AND BETTER USAGE OF WATER RESOURCES

OCEANOGRAPHY AND MARINE RESOURCES

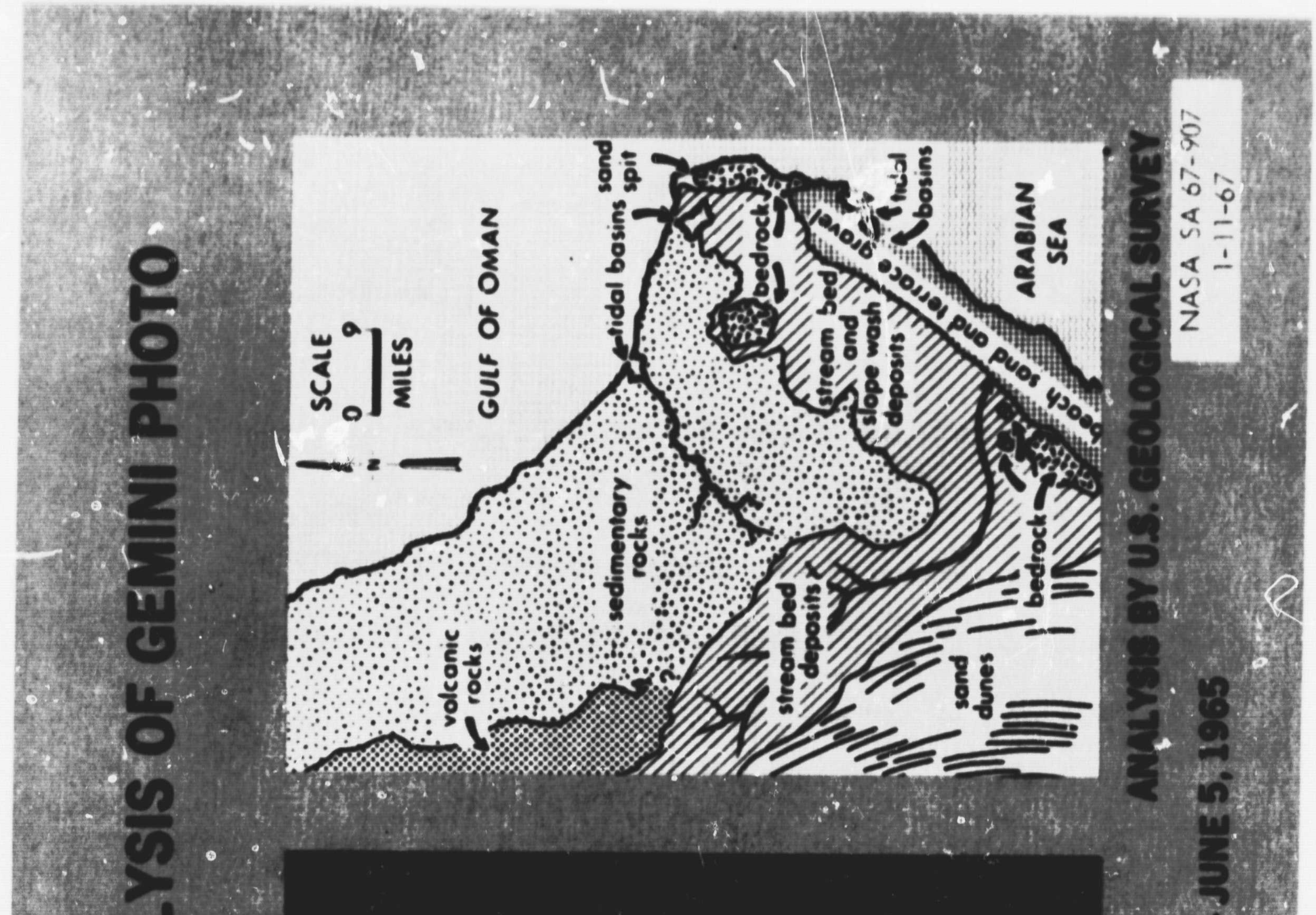
TO AID IN OCEAN TRANSPORTATION AND IN BETTER UTILIZATION OF FISHERIES

NASA SA 67-931
1-16-67

GEOLOGICAL ANALYSIS OF GEMINI PHOTO
(Fig. 30)

One of the most obvious and immediately useable potentials of earth resources satellites is that of geology, as illustrated in this figure. Satellite geodetic mapping on a global basis is less expensive than accomplishing the same task with aircraft. Furthermore, the overview in color provides information not readily discernible in aircraft mosaics. In addition to the scientific benefits of such geodetic surveys, there are many practical applications including land development and the location of oil and mineral deposits. Were time to permit, each of the other aforementioned earth resources areas could be illustrated in an equally dramatic fashion.

Figure 30


GEOLOGICAL ANALYSIS OF GEMINI PHOTO
PHOTOGRAPH
SCALE
0 9
MILES
GULF OF OMAN
tidal basins
sand spit
volcanic rocks
sedimentary rocks
bedrock
stream bed and slope wash deposits
beach sand and terrace gravel
tidal basins
stream bed deposits
sand dunes
bedrock
ARABIAN SEA
ANALYSIS BY U.S. GEOLOGICAL SURVEY
OMAN - JUNE 5, 1965
NASA SA 67-907
1-11-67

EARTH RESOURCES SURVEY SATELLITES
(Fig. 31)

The survey of earth resources from orbit may be conducted with either manned or automated satellites and it remains to be determined which will carry the bulk of the work load. Perhaps the sensors will be developed as part of the operation of a manned earth-orbiting space station and later incorporated into an operational automated survey satellite of the type shown here. On the other hand, initial developments could be made using improved TOS weather satellites or the Nimbus. Whichever approach is used, the indicated technology will be required.

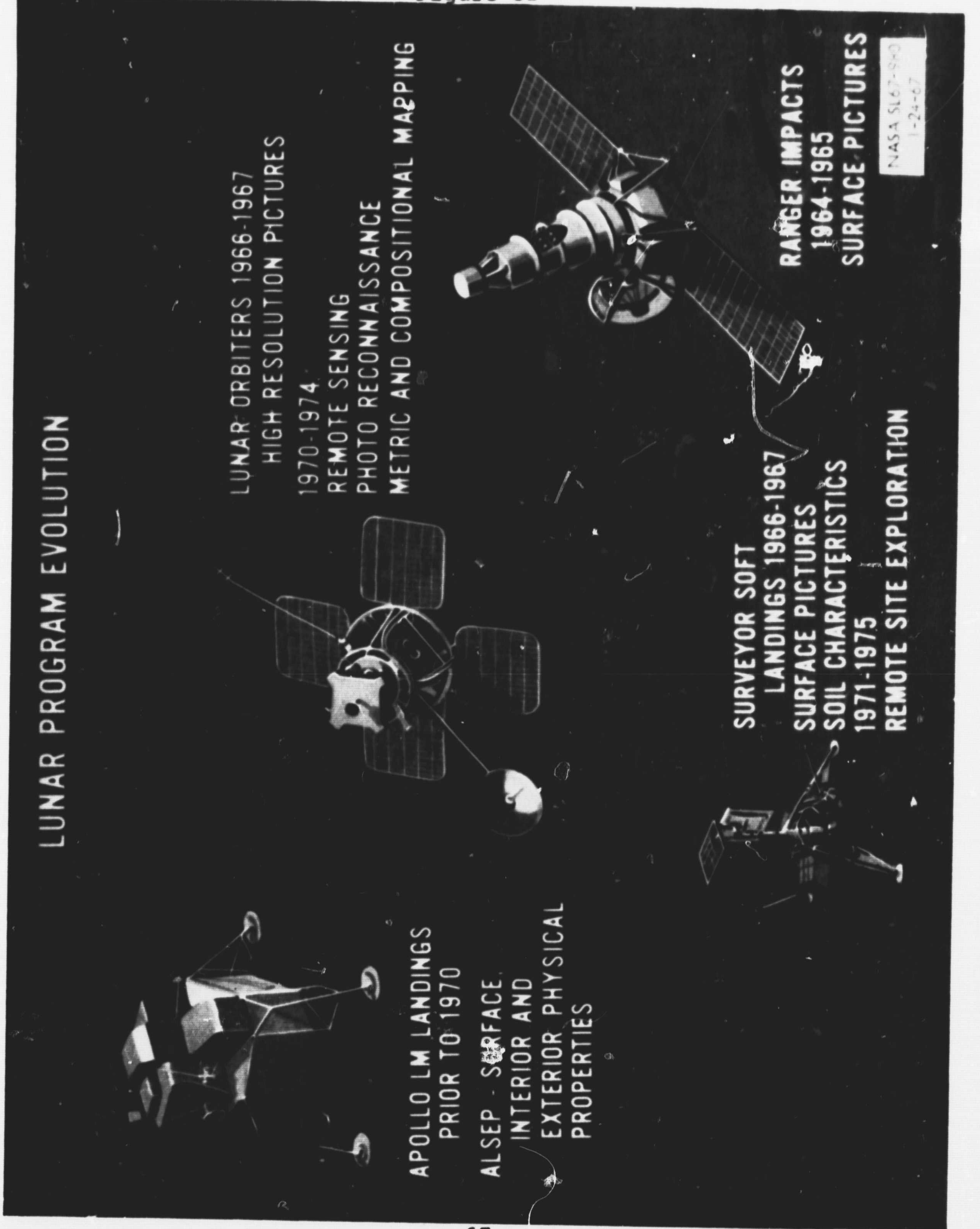
Figure 31


EARTH RESOURCES SURVEY SATELLITES
NEW TECHNOLOGY REQUIREMENTS
• MULTI-SPECTRAL SENSORS
• HIGHER RESOLUTION SENSORS
• IMPROVED SENSITIVITY SENSORS
• ACCURATE SENSOR POINTING SYSTEMS
• INTERROGATION & RELAY SYSTEMS
• DATA SELECTION & PROCESSING SYSTEMS
• IN-ORBIT REPROGRAMMING
• BROADBAND DATA TRANSMISSION SYSTEMS
• DATA CORRELATION SYSTEMS
NASA S67-2170
4-14-67

LUNAR PROGRAM EVOLUTION
(Fig. 32)

The evolution of the country's program to explore the Moon has proceeded in a logical manner and points the way to the planets. Ranger gave us an early view of the lunar surface at high resolution and permitted us to refine both our concepts of the lunar small-scale topography and to plan more effectively our later explorations of the Moon. The combination of the Lunar Orbiter working in conjunction with the Surveyor has proven to be an extremely effective approach both in the search for manned landing areas and for broadening our understanding of the nature of the Moon. With the landing of Apollo, we will be able to carry out selective sampling of the lunar material and to emplace semi-permanent automated scientific stations. Still further into the future, man will carry out geological traverses with the aid of vehicular transportation.

Figure 32


LUNAR PROGRAM EVOLUTION
LUNAR ORBITERS 1966-1967
HIGH RESOLUTION PICTURES
1970-1974
REMOTE SENSING
PHOTO RECONNAISSANCE
METRIC AND COMPOSITIONAL MAPPING
APOLLO LM LANDINGS
PRIOR TO 1970
ALSEP - SURFACE
INTERIOR AND
EXTERIOR PHYSICAL
PROPERTIES
SURVEYOR SOFT
LANDINGS 1966-1967
SURFACE PICTURES
SOIL CHARACTERISTICS
1971-1975
REMOTE SITE EXPLORATION
RANGER IMPACTS
1964-1965
SURFACE PICTURES

SURVEYOR I RESULTS
(Fig. 33)

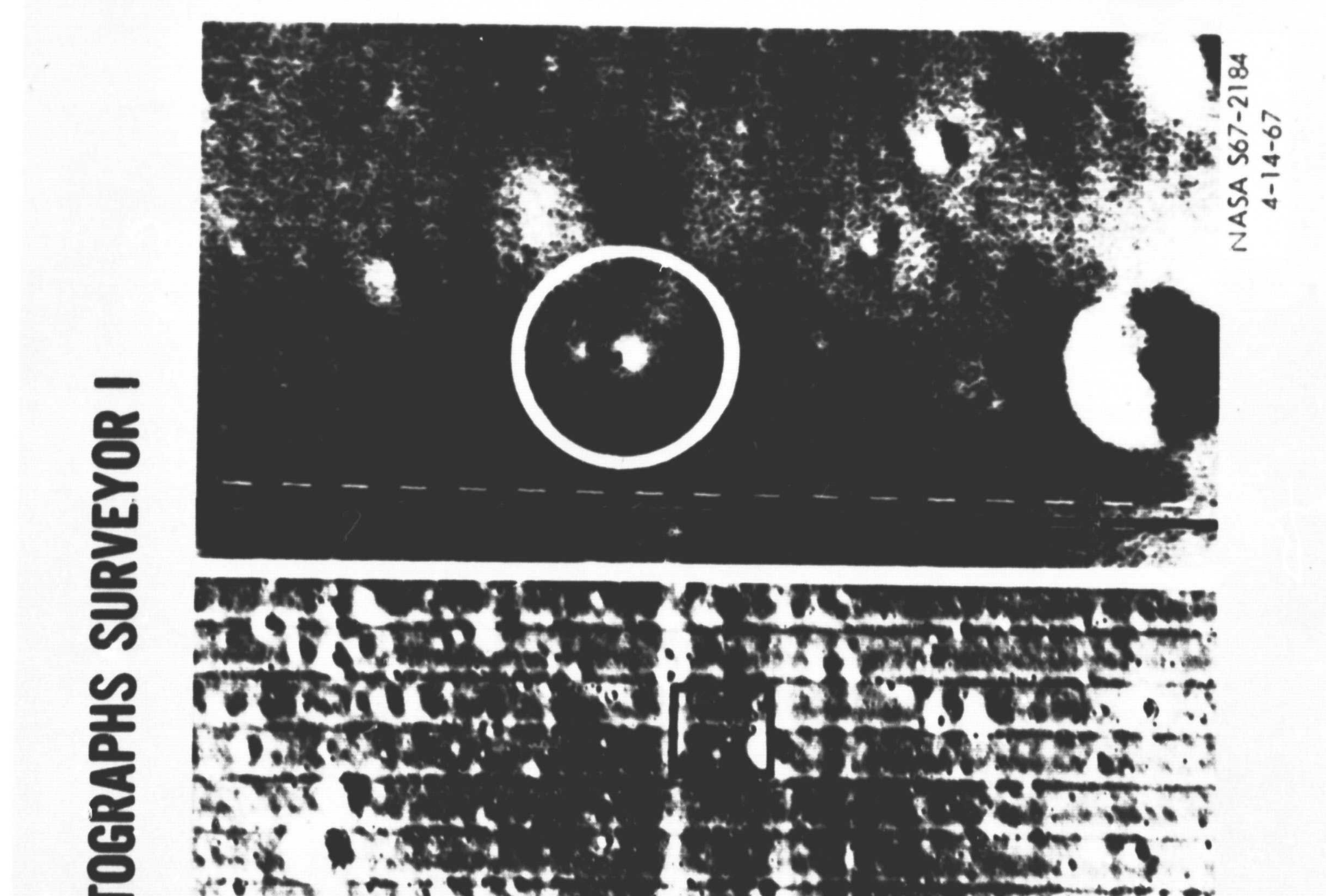
The results of these programs are summarized in the next few figures. Here we see some good examples of the Surveyor I photography. The mosaic in the lower part of the figure is a partial panorama which shows a cratered and debris-strewn plain in the Ocean of Storms. Using the zoom lens capability of Surveyor's television camera, the 1" to 2" footprint made by each of Surveyor's landing pads is shown in the upper left. The material is seen to consist of fine-grained particulate material of moderate cohesiveness. It was interpreted to have a consistency much like that of dry silt. It could be readily scooped up with one's hands and yet, with a bearing strength of about 6 lbs. per sq. in. at the surface, would be sufficiently firm for LEM landings and for the astronauts to walk upon. A magnification of one of the many rocks which litter the lunar surface is shown in the top center. In the upper right is a distant rock field associated with a large crater in the vicinity of the Surveyor landing site.

Figure 33

ORBITER III PHOTOGRAPHS SURVEYOR I
(Fig. 34)

The first three Lunar Orbiters surveyed about 35,000 square miles of more than 20 primary Apollo landing sites. In addition, some 600,000 square miles area of secondary sites were photographed plus over 3-1/2 million square miles of lunar far side. This figure shows an oblique photograph taken of the Surveyor I landing area with an illustration of the manner in which triangulation, based on Surveyor's mountain photography, was used to help pinpoint Surveyor's location. The center photograph shows the Surveyor landing site as viewed with the Orbiter's high resolution (1 meter) camera. The right-hand photograph is an enlargement which shows the Surveyor itself, its shadow, and the rock craters which correlate precisely with the panorama from the surface. This combination of surface and orbital photography greatly enhances our understanding of the terrain and increases our ability to extrapolate our findings to other areas.

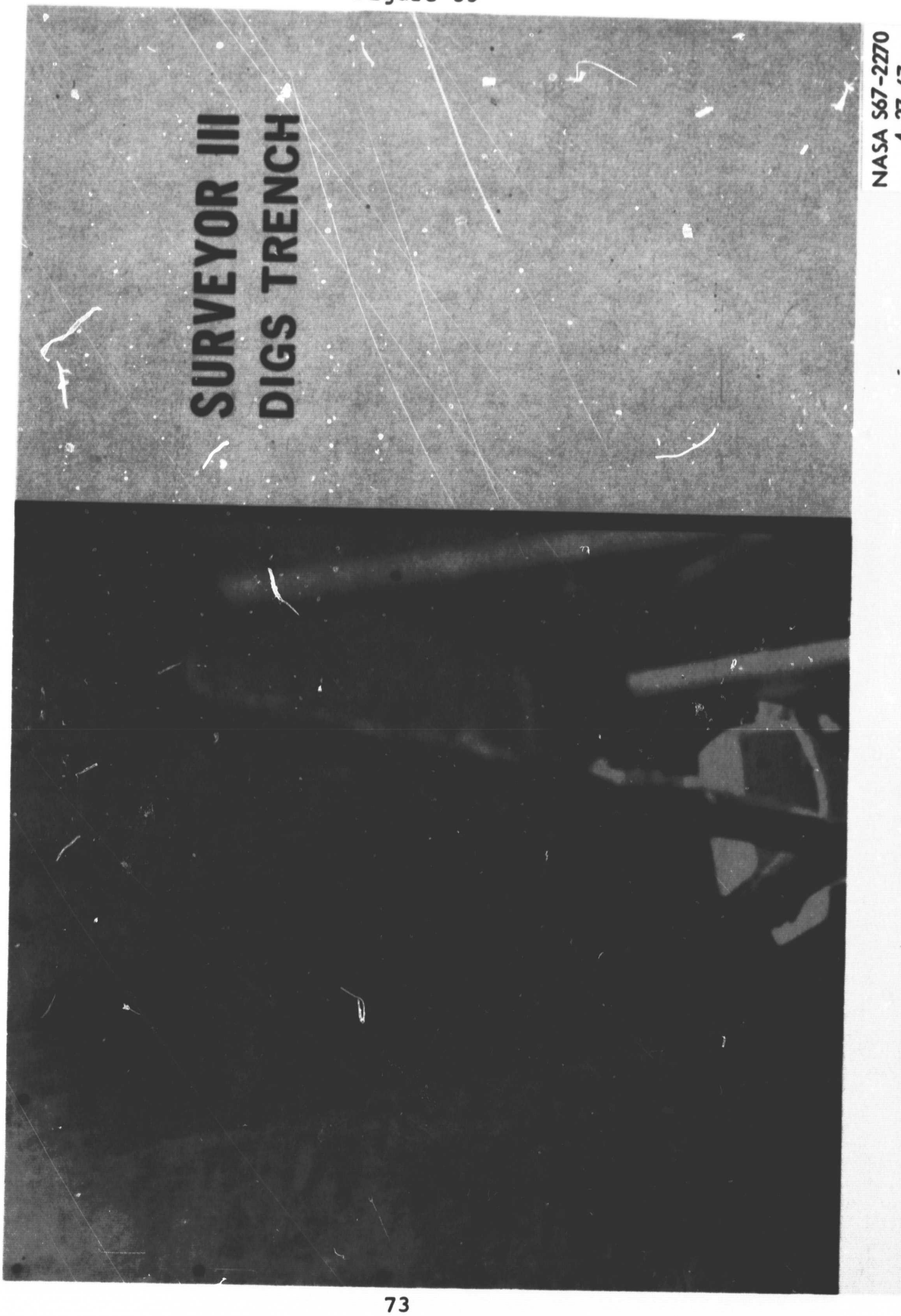
Figure 34



SURVEYOR III DIGS TRENCH
(Fig. 35)

Surveyor III landed in a crater on the Moon at a position 23.4° West and 2.9° South in one of the potential Apollo landing zones. It was equipped with a small digging device which in this photograph has partially completed digging a trench. This device is equipped with strain gages and has been calibrated against known materials on the earth so as to yield relatively good information on the mechanical properties of the lunar surface to a depth of about 18 inches. At the time of this writing, the experimenters had confirmed that the material was composed of moderately cohesive fine particles plus larger chunks of debris. It further showed that the bearing strength in the top inch or two did not exceed the 6-pound-per-square-inch value inferred from Surveyor I, but it seemed somewhat stronger beneath the surface. It is hoped that the experimenters will be prepared to release more information by the time this paper is presented.

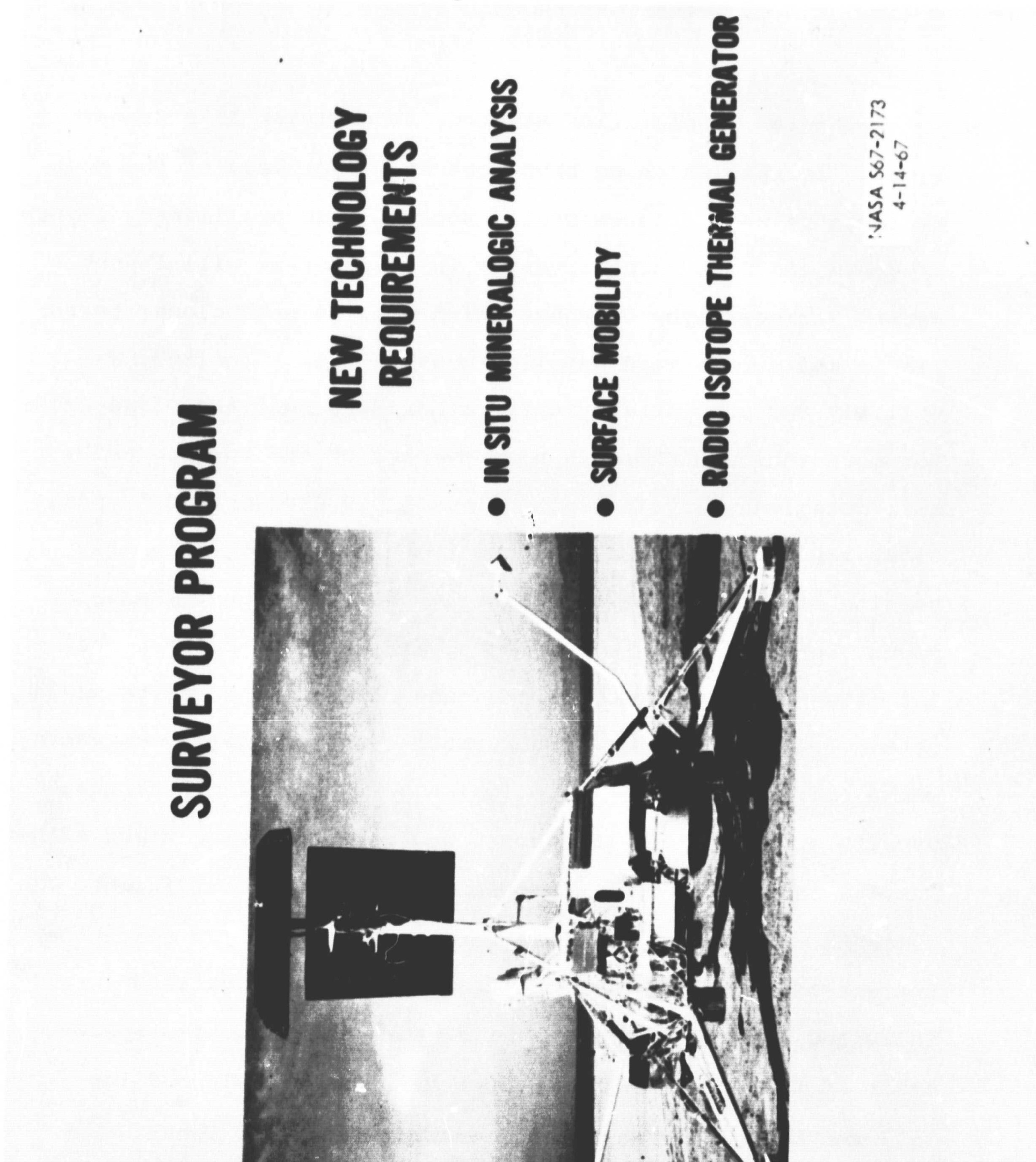
Figure 35



SURVEYOR PROGRAM
(Fig. 36)

The post-Apollo program for lunar exploration has been under careful study for several years. Our hopes include an extended capability for manned exploration, possibly combined with continued utilization of Surveyor and Orbiter-type equipment to investigate regions not suited for manned exploration or perhaps in advance of eventual manned exploration. The first priority is to increase man's mobility on the surface. Beyond that, the Surveyor can be uprated to do a more complete examination of its landing area. This would include providing advanced instrumentation to conduct mineralogic analysis, provision for surface mobility with small lightweight rovers, and provision of nuclear power supplies to supplement solar power.

Figure 36

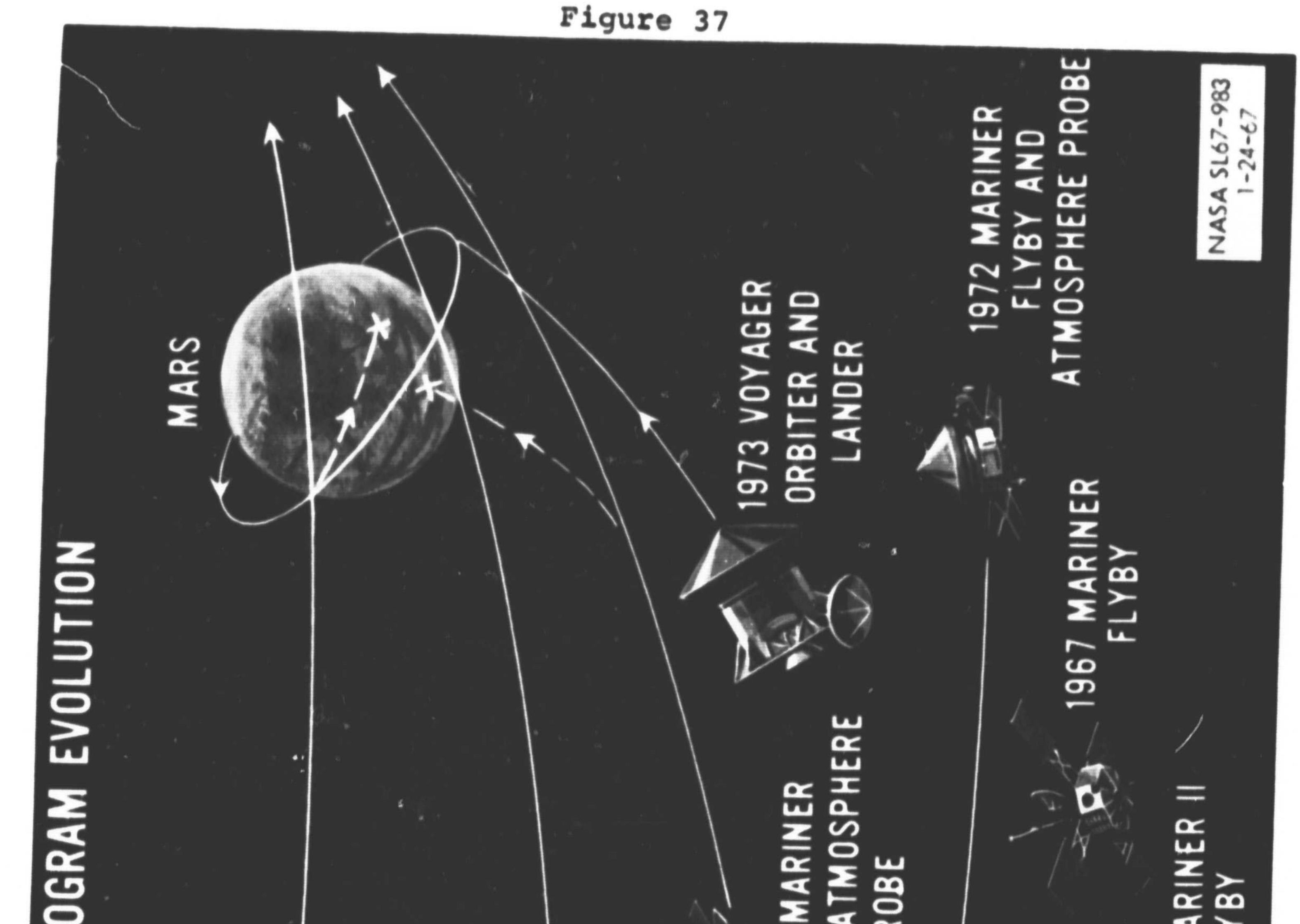

SURVEYOR PROGRAM
NEW TECHNOLOGY REQUIREMENTS
● IN SITU MINERALOGIC ANALYSIS
● SURFACE MOBILITY
● RADIO ISOTOPE THERMAL GENERATOR
NASA S67-2173
4-14-67

PLANETARY PROGRAM EVOLUTION
(Fig. 37)

Planetary exploration strategy is evolving in a manner similar to that which we have used so effectively on the Moon. Mariners II and IV successfully accomplished preliminary flybys of Venus and Mars respectively. This summer we will launch a second Mariner flyby of Venus which will go much closer to the planet and obtain more detailed measurements. In 1969, we will fly two considerably uprated Mariners past the planet Mars for more thorough photographic coverage of the surface and a more detailed analysis of the atmospheric density and composition. By 1971 and 1972, we hope to have modified this 1969 version of the Mariner to again fly past the planets Mars and Venus, but this time to deliver several-hundred-pound probes into their atmospheres. In the case of Mars, this probe would obtain detailed pressure, temperature, and composition measurements, but would not survive impact. Because of the increased density of the Venus atmosphere, however, the probe might either survive landing or might release a balloon to float in the atmosphere of Venus for continued observations. To reach the surface of Mars and carry out scientific investigations including a search for extraterrestrial life requires spacecraft of the Voyager class. Such missions are planned for 1973 and beyond for Mars, and somewhat later for Venus.

Voyager constitutes the most important U.S. step in space exploration since the initiation of Apollo.

Figure 37


PLANETARY PROGRAM EVOLUTION
MARS
VENUS
1964-1965 MARINER IV FLYBY
1969 MARINER FLYBY
1971 MARINER FLYBY & ATMOSPHERE PROBE
1973 VOYAGER ORBITER AND LANDER
1972 MARINER FLYBY AND ATMOSPHERE PROBE
1967 MARINER FLYBY
1962 MARINER II FLYBY
NASA SL67-983
1-24-67

MARINER IV - MARS PHOTOS
(Fig. 38)

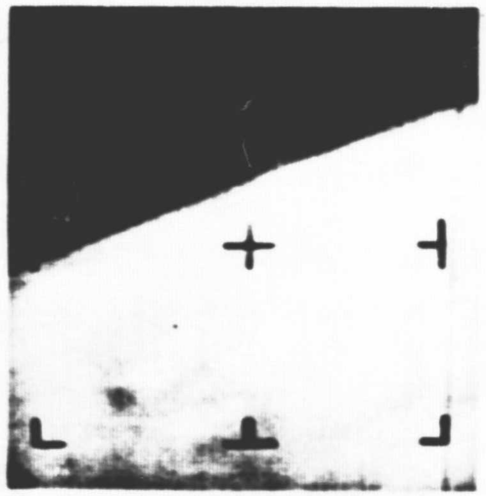
The prior results of our planetary exploration program are highlighted by these four photographs of Mars obtained by Mariner IV in 1965. For the first time, we observed the Mars topography to be remarkably like that of the Moon with a crater density and appearance closely corresponding to those observed on the Moon. These observations were based on a 1% sampling and we may expect some surprises, however. Although the Martian atmosphere was measured to be less than 1% as dense as that of the earth, laboratory tests have shown that such an atmosphere with a small amount of water is sufficient to sustain some types of life in the Martian temperature cycle. Whether such life exists on Mars, has existed in the past, or might be sustained in the future is one of the most compelling questions in the space program, and, for that matter, in science generally. It has been endorsed by the Space Science Board as one of the prime goals of the space program for the 1970's.

Voyager is designed to reach this goal.

Figure 38

MARINER IV- MARS PHOTOS

NUMBER 1

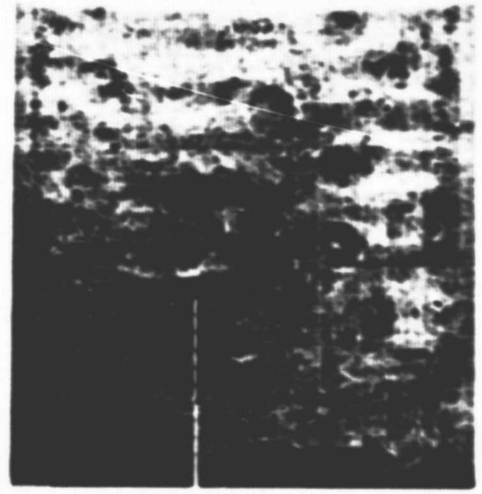


ALTITUDE: 10.500 MILES

AREA: PHLEGRA, 35 DEG. N. LATITUDE × 172 DEG. E. LONGITUDE.

SCALE : 410 MILES ALONG THE LIMB × 800 MILES

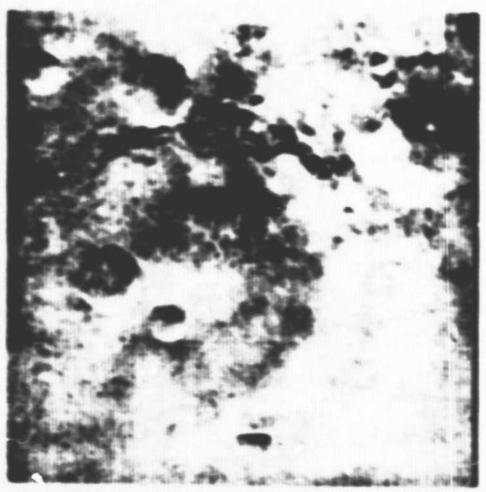
NUMBER 9



ALTITUDE: 8100 MILES

AREA: MARE SIRENUM, 23 DEG. S. LATITUDE, ×191 DEG. E LONGITUDE

SCALE: 170 MILES E-W × 160 MILES N-S (NORTH AT TOP)

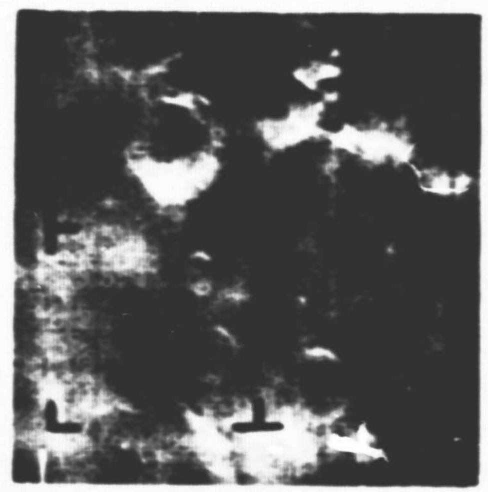


NUMBER 11

ALTITUDE: 7.800 MILES

AREA: ATLANTIS, 31 DEG. S. LATITUDE × 197 DEG. E. LONGITUDE

SCALE: 170 MILES E-W × 150 MILES N-S (NORTH AT TOP)



NUMBER 14

ALTITUDE: 7.600 MILES

AREA: PHAETHONTIS, 41 DEG. S. LATITUDE × 208 DEG. E. LONGITUDE

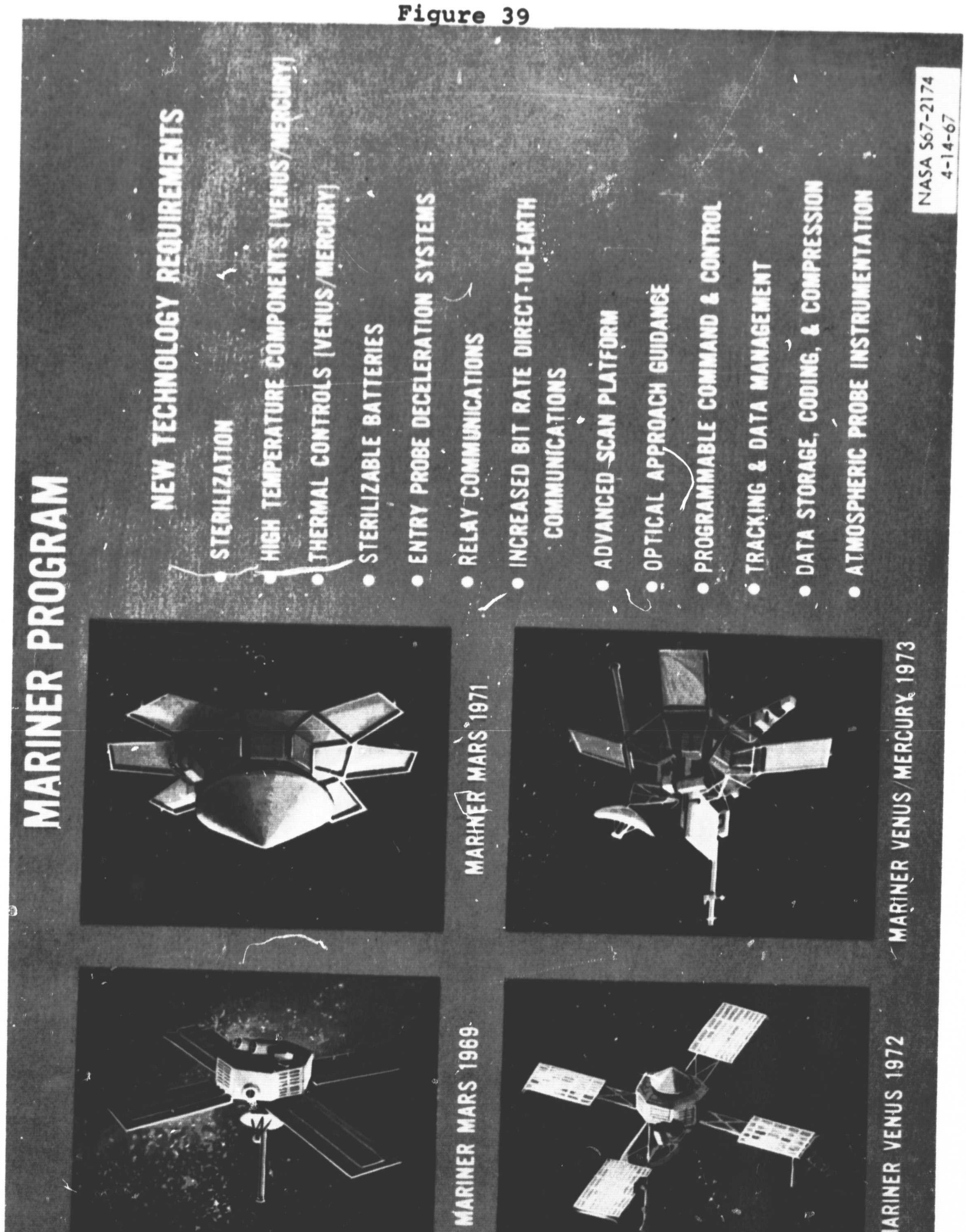
SCALE: 170 MILES E-W × 140 MILES N-S (NORTH AT TOP)

NASA SP 66-161
1-15-66

MARINER PROGRAM
(Fig. 39)

The Mariner spacecraft evolution is shown in this figure, including those new technological requirements needed to support them. It is important to notice that the Mariner '71 will serve as a technical pilot model or pacesetter for the Voyager '73 missions in that many of the new technologies required for Voyager will also be required for Mariner. Furthermore, the Mariner '71 data return will be applicable to refining the Voyager hardware, its mission profile, and its operations to obtain maximum returns from Voyager.

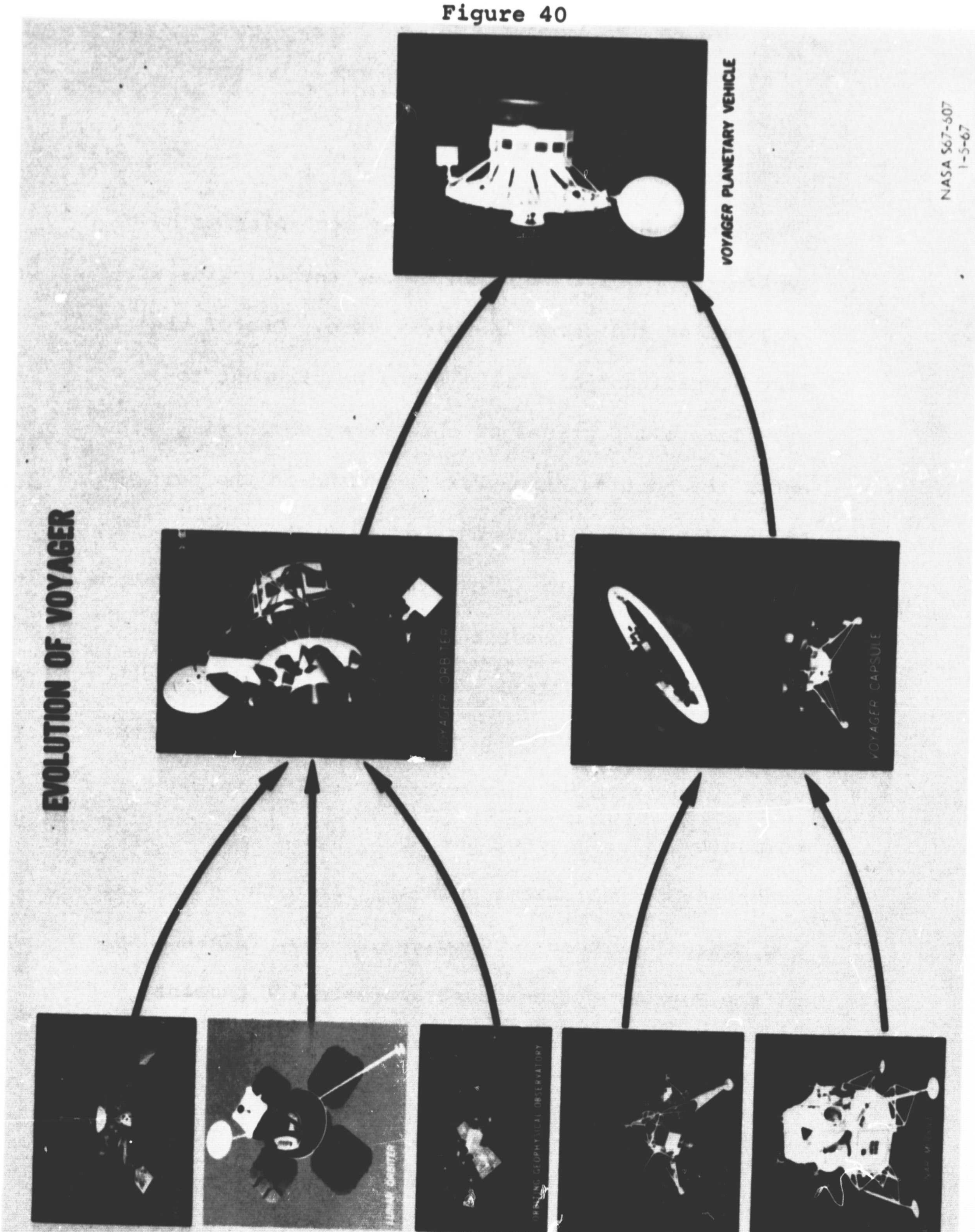
Figure 39


MARINER PROGRAM
NEW TECHNOLOGY REQUIREMENTS
• STERILIZATION
• HIGH TEMPERATURE COMPONENTS (VENUS/MERCURY)
• THERMAL CONTROLS (VENUS/MERCURY)
• STERILIZABLE BATTERIES
• ENTRY PROBE DECELERATION SYSTEMS
• RELAY COMMUNICATIONS
• INCREASED BIT RATE DIRECT-TO-EARTH COMMUNICATIONS
• ADVANCED SCAN PLATFORM
• OPTICAL APPROACH GUIDANCE
• PROGRAMMABLE COMMAND & CONTROL
• TRACKING & DATA MANAGEMENT
• DATA STORAGE, CODING, & COMPRESSION
• ATMOSPHERIC PROBE INSTRUMENTATION
MARINER MARS 1969
MARINER MARS 1971
MARINER VENUS 1972
MARINER VENUS/MERCURY 1973
NASA S67-2174
4-14-67

EVOLUTION OF VOYAGER
(Fig. 40)

The Voyager system has developed over a period of years beginning as far back as 1960, when we determined that a spacecraft of the Saturn-launched class would be required for automated surface exploration of Mars. Since then, the system concept has evolved logically from other developments in the space program. For example, the Mariner IV developed the technology to navigate to other planets with great precision. The Lunar Orbiter developed the technology to orbit a distant celestial object and to adjust the orbit for observational purposes with great precision. The Orbiting Geophysical Observatory and the Nimbus developed the technology of continuous and simultaneous pointing towards the planetary surface and celestial objects. The orbiting portion of the Voyager system will directly make use of these technologies. The landing portion of the Voyager system has evolved from the Surveyor and the Apollo Lunar Module. Surveyor first developed the technology of conducting a closed-loop rocket landing under the control of an onboard radar system. The LM has refined this system. The ballistic missile systems and the Apollo command module have developed the aeroshell technology for thermal protection during aerodynamic braking. The combined Voyager capsule assembly and the Voyager orbiter constitute the planetary vehicle, two of which will be launched with a single Saturn V at each opportunity.

Figure 40

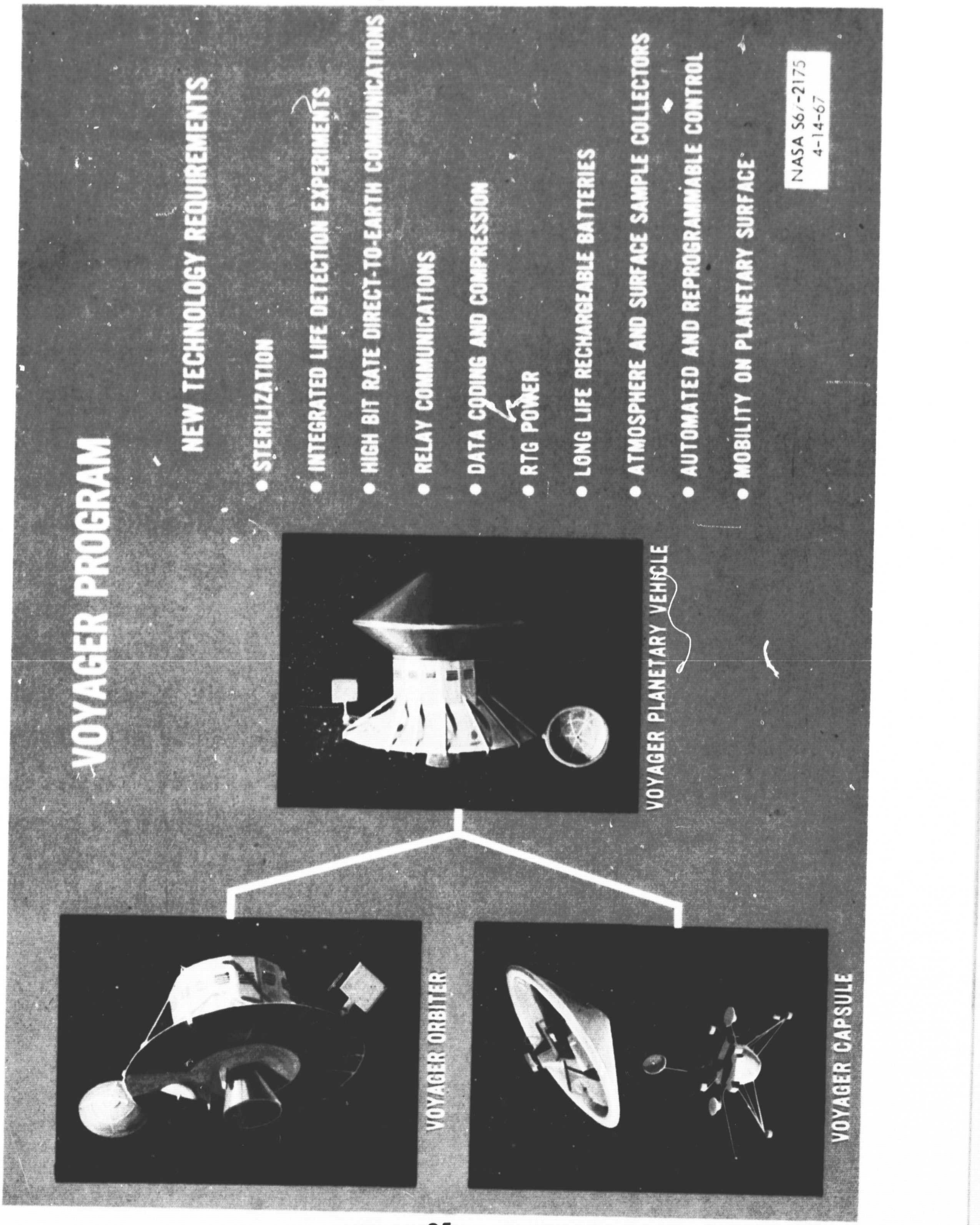


EVOLUTION OF VOYAGER
VOYAGER PLANETARY VEHICLE
VOYAGER ORBITER
VOYAGER CAPSULE
NASA S67-507
1-5-67

VOYAGER PROGRAM
(Fig.41)

Although many of the Voyager technologies have evolved from prior experience, new technologies are required as indicated in this figure. One of the most significant of these is the requirement to sterilize all portions of the system which will enter the Martian atmosphere and land on the surface. An equally demanding technology is that of developing an integrated set of life detection experiments which would, in effect, constitute an automated and re-programmable biological laboratory. Both of these technologies are extremely challenging for the aero-space industries of this country and the biological community. In my view, they hold great promise for important technological spin-off for both industrial and medical purposes. Needless to say, reliability of the Voyager systems must approach 100 percent.

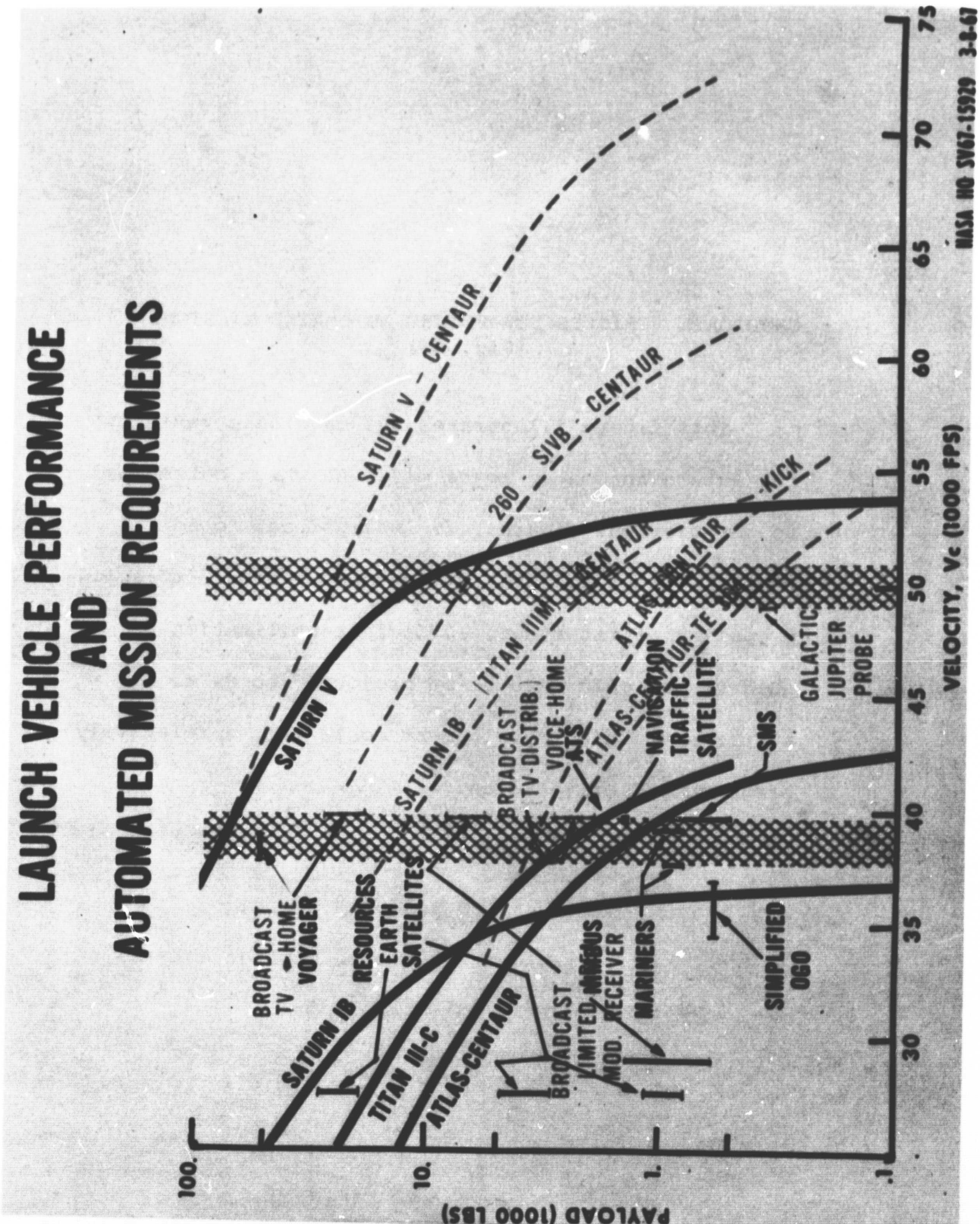
Figure 41


VOYAGER PROGRAM
NEW TECHNOLOGY REQUIREMENTS
• STERILIZATION
• INTEGRATED LIFE DETECTION EXPERIMENTS
• HIGH BIT RATE DIRECT-TO-EARTH COMMUNICATIONS
• RELAY COMMUNICATIONS
• DATA CODING AND COMPRESSION
• RTG POWER
• LONG LIFE RECHARGEABLE BATTERIES
• ATMOSPHERE AND SURFACE SAMPLE COLLECTORS
• AUTOMATED AND REPROGRAMMABLE CONTROL
• MOBILITY ON PLANETARY SURFACE
VOYAGER PLANETARY VEHICLE
VOYAGER ORBITER
VOYAGER CAPSULE
NASA S67-2175
4-14-67

LAUNCH VEHICLE PERFORMANCE AND AUTOMATED MISSION REQUIREMENTS
(Fig. 42)

The launch vehicles required for the various missions I have outlined in this talk are summarized in this figure. The current family of launch vehicles through the Atlas Centaur and Titan III-C will suffice for some of the new missions. The most demanding of the missions - Voyager - is adequately handled by the Saturn V. A number of missions are identified, however, for which no existing launch vehicle adequately fills the bill. For example, two classes of broadcast TV satellites are too heavy for the existing launch vehicles other than Saturn V, and too light to justify the use of the costly Saturn V. In addition, the very-high-velocity Jupiter missions cannot be launched with any current launch vehicle. These deficiencies can be met with relatively simple combinations of existing stages, however. For example, the addition of a solid propellant kick stage to the Atlas Centaur will provide marginal capability for the Galactic Jupiter probe. Still better capability can be provided by mating the Centaur stage to the Titan III-C, the Titan III-M, or the Saturn I. This will also provide a vehicle adequate to handle the initial television broadcast satellites. Broadcast satellites for TV directly into home receivers, however, will require a still greater capability which could be met by the Saturn V, but more economically by a 260" solid-propellant first stage carrying Saturn IV-B and Centaur upper stages.

Figure 42

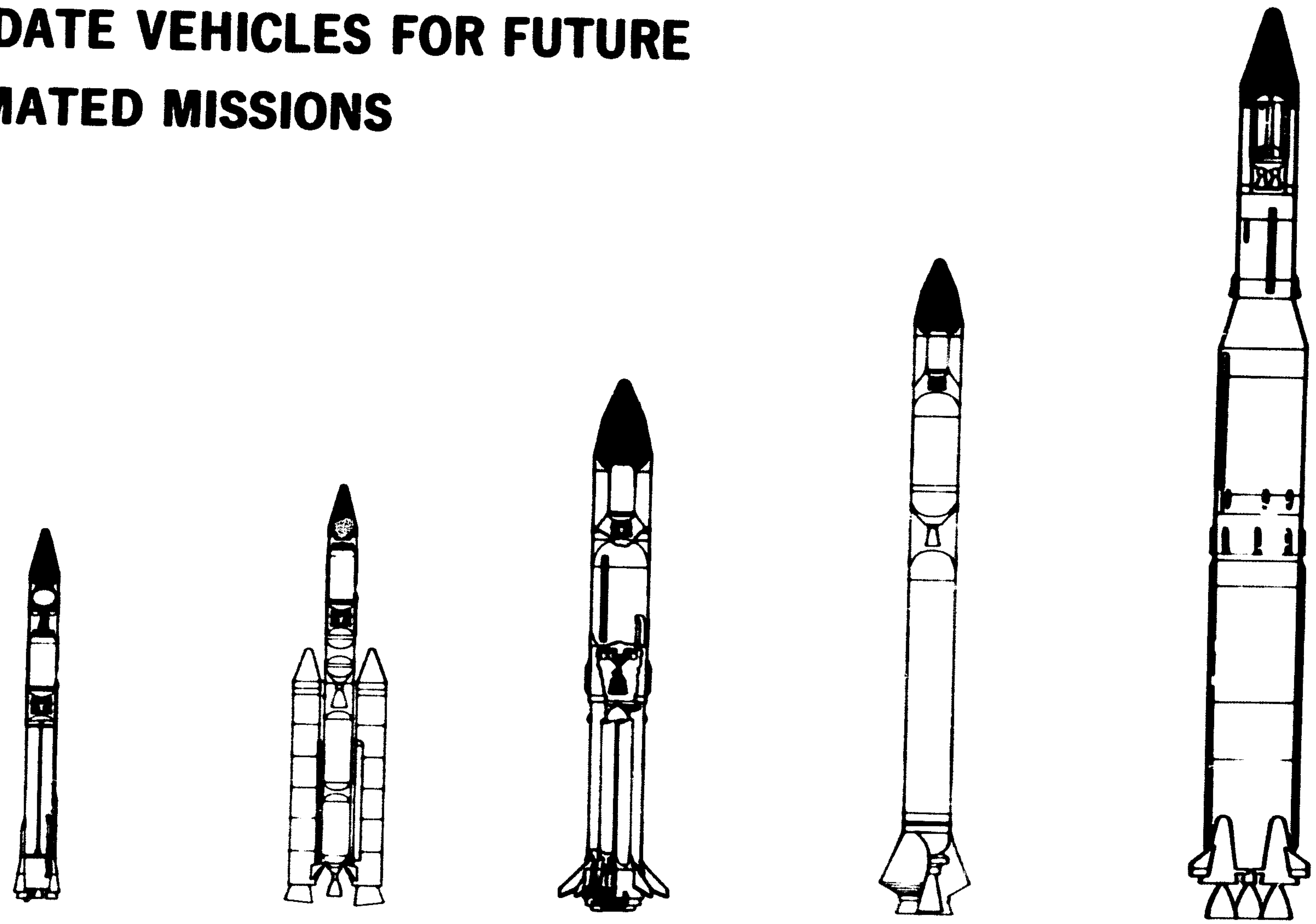

LAUNCH VEHICLE PERFORMANCE
AND
AUTOMATED MISSION REQUIREMENTS
PAYLOAD (1000 LBS)
VELOCITY, Vc (1000 FPS)
SATURN V
SATURN V - CENTAUR
260 - SIVB - CENTAUR
SATURN IB
TITAN III-C
ATLAS-CENTAUR
KICK
BROADCAST TV - HOME VOYAGER
RESOURCES EARTH SATELLITES
BROADCAST TV-DISTRIB.)
VOICE-HOME
ATS
NAVIGATION TRAFFIC SATELLITE
GALACTIC JUPITER PROBE
SMS
MARINERS
SIMPLIFIED OGO
NASA HQ SV67-15929 3-8-67

CANDIDATE VEHICLES FOR FUTURE AUTOMATED MISSIONS
(Fig. 43)

This figure illustrates the candidate vehicles for future automated space missions which correspond to the previous figure. It is important to note that, in order to justify development of a 260" solid-propellant first stage, sufficient utilization of this stage would have to be projected so as to amortize the high development costs over a relatively large number of vehicles.

Figure 43

CANDIDATE VEHICLES FOR FUTURE AUTOMATED MISSIONS



PAYLOAD	ATLAS/CENT.-KICK	T-III-C- CENTAUR	SIB -CENTAUR	260"-SIVB-CENTAUR	SATURN V- CENTAUR
@ V_C= 40,000 FPS	2300 - 3000 LBS	7600 LBS	11,000 LBS	23,000 LBS	72,000 LBS
@ V_C= 49,000 FPS	475 - 975 LBS	1500 LBS	2,500 LBS	7,900 LBS	29,000 LBS
@ V_C =70,000 FPS	—	—	—	—	1,500 LBS

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CONCLUDING REMARKS

This summary of future automated space missions has included only those missions which are relatively well-defined and for which we hope to initiate developments within the next few years. A vigorous national space program which will maintain our world leadership in space may be expected to place into operation most of the systems I have outlined within the next decade. In the more distant future, we are beginning to identify still more exciting opportunities for the exploration and utilization of space.

It seems clear to me that this program will ultimately pay for itself not merely in scientific knowledge and technological spin-off, but in direct savings of labor required of the peoples of the world in the conduct of a host of daily earthly activities.

* * *